ALLIS-CHALMERS Electrical REVIEW

Second Quarter, 1951

THIS PEAKING STATION deep in the hills of southern Idaho is one of five major hydroelectric projects in the Malad river electrification development. Consisting of four modified umbrella type outdoor vertical synchronous generators rated 15,000 kw, 120 rpm, 17,500 kva, unit operates at full load on an average of ten hours daily. The two foreground units have higher air housings to accommodate Kaplan turbine heads, while the other two units are driven by fixed blade propeller turbines.

Station contains telemetering equipment that records operating conditions at the remotely controlled hydro plant located three miles upstream and shown on pages 18 and 19. The five-station development is an integral part of the Northwest power pool.

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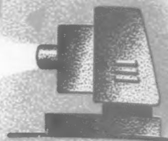
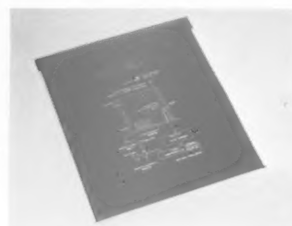
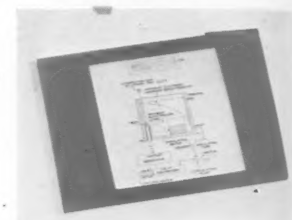
How to Prepare Better Slides . . .



Applying a few simple tried and proven steps in preparing drawings for slides improves value of visual training aids.





by R. CAMPANA*
Atomic Power Dept.
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VISUAL AIDS are becoming an increasingly important medium of transmitting information by industry, business, and public and private institutions. Motion pictures, signs, posters, slides, and other illustrative means provide the most effective and widely used methods of presenting useful and persuasive information to groups of people. Such aids are particularly useful to industry where new and complicated machinery is being introduced constantly. Machine design, installation, operation, maintenance, and the other necessary details have to be described and illustrated simply, clearly, and completely if the users of a particular piece of equipment are expected to achieve the optimum results for which it was built.

The "still" picture, or slide, is one of the lecturer's most effective and economical mediums for presenting detailed information to his intended group. This, however, resolves itself into several problems which must be solved before a suitable slide presentation can be formed. Most prominent among these concerns itself with the selection of the best drawing for the slide, or what is the best way of making such a drawing.

There are certain guides to follow that establish standard line and letter sizes for standard drawing sizes that can be used as a yardstick for the making of clear, effective slides. The purpose of these recommendations is to establish standards by which drawings which have already been produced may be evaluated for their ability to make good slides and to indicate a few simple rules which govern the use of slides after they have been produced.

Please the eyes

When considering the size of lines and letters regardless of where they may appear, it is necessary to consider the limitations of the human eye as an optical instrument. In addition to size, such factors as brightness of the object, its contrast, its distance from the viewer, and the time the eye pauses while scanning the parts of an object play an important role in the ability of the eye to see detail. (See Figure 1.)[1] In this instance, brightness will be considered as sufficient from a properly designed projection instrument and between 50 and 100 millilamberts. Also contrast will be considered near maximum, that is black on white. The time the eye pauses will be regarded as between 0.3 second and 0.075 second, the longest and shortest values usually involved in critical seeing.[1] Size and distance of the viewer from the object thus remain as the chief factors for discussion although those mentioned above must not be entirely disregarded.

The capacity of the eye to distinguish two adjacent points, one from the other, is called the "resolving" power of the eye, and is usually expressed as the angle or tangent of the angle which the object being viewed subtends at the eye. Every optical instrument such as a microscope has its own resolving power which is dependent on the physical properties and the arrangement of the optical parts of the instrument. If the angle subtended at the eye by two adjacent points is less than that corresponding to the resolving power of the optical system being employed, then the two points overlap or appear as one. For example, if the points are black on white, the black points might not appear at all because the separation of the surround-

* This paper won first prize in the 1951 Allis-Chalmers Engineers Society Authors' Contest, open to all graduate training students in the Allis-Chalmers organization.

ing white points might be below the critical value and the white points therefore would overlap or appear as a single white point.

The critical angle corresponding to the resolving power of the eye is just under one minute. However, one minute is generally taken for practical purposes[2] and will be used here.

Line and letter sizes are important

If x is permitted to equal the thickness of a line (Figure 2), to be observed from a distance L and the angle θ is thereby subtended at the eye, then

$$\operatorname{Tan} \theta = x/L$$

$$\text{but if } \theta = 1 \text{ minute} \qquad \text{(Equation 1)}$$

$$x = .00029\ L$$

When the desired units of measure are applied to Equation 1, x becomes immediately available in the applied units as the threshold size of the lines which are to be seen distinctly.

Lower case letter size

By considering the line and space requirements of the letters of the alphabet, the minimum height and width of letters may be found as a multiple of the critical unit. The critical unit is defined as the distance between two points which will subtend an angle of one minute at the eye. The critical unit is thus proportional to the distance (L). To establish letter size, it is necessary to assume that while it is desirable to be able to see the letters easily and distinctly, it is also necessary to conserve space in order to place a useful amount of information on the drawing and slide. Accordingly, the line thickness and space between lines will be made greater than the critical unit but not much greater.

Turning to the letters themselves, the letter M, as shown in Figure 3a, is found to be the widest letter. From the foregoing material, lines I, II, III, and IV must be at least the critical unit in width. If the total distance between spaces 1 and 4 were only a single critical unit then everywhere above the bottom-most edge of the letter, lines I and II would be less than a critical unit apart and thus would appear to overlap. To avoid this, the additional spaces 2 and 6 are added to spaces 3 and 5 respectively. It is now apparent that the width of the letter must be seven times the critical unit.

Consider next the letter G (Figure 3b) since it will require the maximum number of critical units in the vertical direction of any letter. Obviously six times the critical unit is necessary. Each letter of the alphabet and each numeral may be analyzed in this manner but since the letters requiring the greatest width and height have been analyzed, and since all letters will be of approximately the same dimensions, analysis of the remaining letters is unnecessary. Also because conventional letters are at least as high as they are wide, the width requirement will be used as the height requirement. The procedure employed above may be used to analyze or construct figures of any type.

Capital letter size

From the discussion on lower case letters the size of capital letters may also be fixed. The height of a capital letter is usually about one-third greater than lower case letters. Thus, if for a case letter

$$y_{case} = 7x \qquad \text{(Equation 2)}$$

where x is the critical unit, then for a capital letter

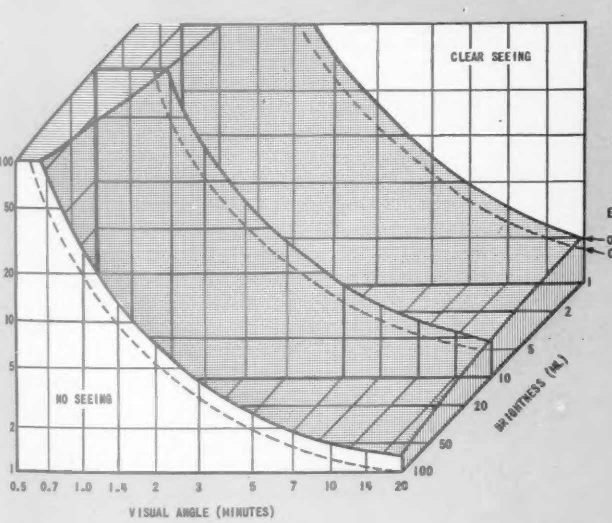
$$Z = 7x + \frac{7x}{3} \quad \text{or}$$

$$Z = 9.33x \qquad \text{(Equation 3)}$$

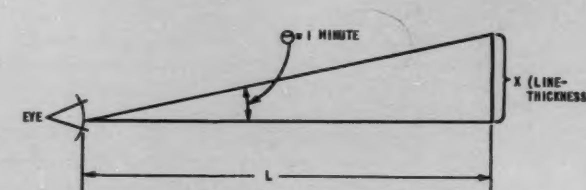
It must be remembered, however, that the values obtained from equations 1, 2, and 3 for the size of lines, lower case letters and capital letters are threshold values and that any number accepted for actual use should be slightly greater than the equations indicate. Failure to observe this will result in blurred or unseeable details on the slides.

Drawing, slide and screen size

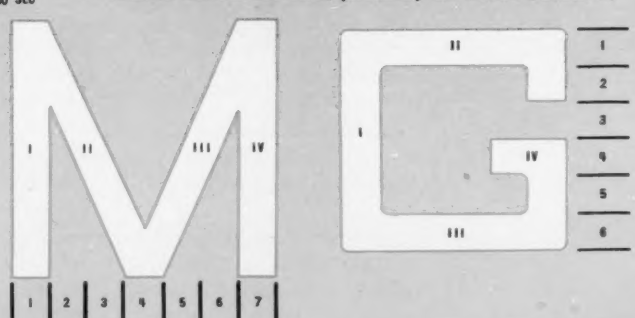
In order to apply the results evolved above to drawings and slides, it is necessary to relate the size of the lines and letters as they are projected on the screen, in the same proportion, to the lines and letters on the drawings of various sizes. To



CURVED SURFACE (dotted space) represents relationship between combinations of size, contrast and brightness for threshold visibility for a constant time of exposure. Effect of various exposure times may be illustrated by raising or lowering this curved surface. **(FIGURE 1)**[1]



RESOLVING POWER of the eye and thus θ, is limited by spherical and chromatic aberrations, diffraction of the light at the pupil, and coarseness of retinal structure, i.e. the cone size and space between cones in the retina, particularly the fovea. **(FIGURE 2)**



VISUAL ANGLE at normal reading distance is about 0.3 degrees or 18 minutes, while letters of a size required for slides have a visual angle of only one minute. Slide letters are small when the distances are compared but the tendency is to make them too small because they are prepared at reading distances. **(FIGURES 3a and 3b)**

state the problem otherwise, how large should the screen size (also slide and drawing size since they are proportional) be with respect to the line and letter size? A screen just large enough to contain one letter of the requisite size for the given distance could be used. But such a system would produce an extremely small amount of information and would not be practical. At the other extreme, the screen could be made quite large with respect to the requisite letter size which would afford a great amount of information. However, the practical limit in this direction is set by the size of the screens which might be available in the rooms or auditoriums where the slides are to be used. A compromise between the two extremes based on experience seems to be the only answer.

TABLE I

MINIMUM LINE AND LETTER SIZE FOR DRAWINGS FROM WHICH SLIDES ARE TO BE MADE

Size of Dwg. (inches)	Distance Dwg. to Furthest Viewer (feet)	Line Size (inches) (x)	Lower Case Letter Size (inches) (7x)	Capital Letter Size (inches) (9.33x)
8½ x 11	4.96	0.0173	0.121	0.161
11 x 17	6.42	0.0223	0.156	0.208
17 x 22	9.92	0.0345	0.241	0.322
22 x 34	12.8	0.0446	0.312	0.416
30 x 42	17.5	0.0609	0.427	0.568
Any See Fig. 6				

All values given above are threshold values.

A compromise worked out by the author indicates that the height of the screen should be one-seventh of the distance from the screen to the furthest observer, or expressed otherwise, the screen should subtend angle of 8 degrees 9 minutes at the farthest observer.

The "screen-distance" ratio or angle for determining the screen size with relation to the distance of the farthest observer is purely arbitrary and is based on judgment of available screen sizes, amount of information that may be presented, and an average size room and audience. Any other value might be chosen if desirable and tables drawn up accordingly, but for general use the one-to-seven ratio is adequate.

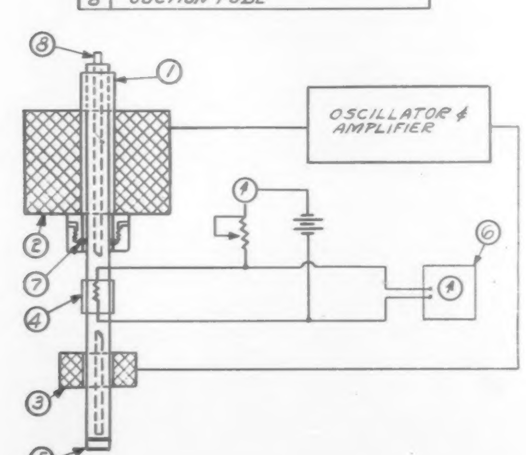
Once the screen-distance ratio has been chosen the sizes of the lines and letters are fixed because the distance is dictated by the ratio and the screen size, and the distance fixes the sizes of the lines and letters by equations 1, 2, and 3. In a like manner, the screen distance ratio may now be applied to drawings of any size thereby retaining the same relative sizes

TABLE II

Departures from the set standards as found in Figure 4

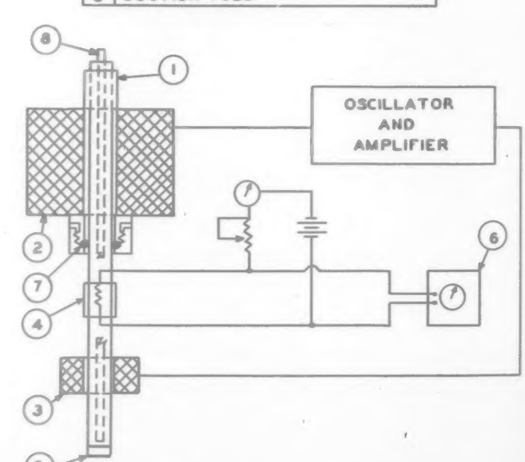
1. The double line separating the column headings from the items under the headings will appear as a single line because of insufficient space between the lines. The line may appear heavy enough to accomplish its purpose, however.
2. Double lines at PT 5 (Test Specimen) will not appear as a double line for the same reason given under item 1.
3. Number "3" of PT 3 — its upper loop has too little space between the lines. Some of the "S's" are similarly at fault as is the "&" of "Oscillator & Amplifier."
4. PT 8 — the broken ends above and below the strain gage (PT 4) will not appear as broken jagged lines. There is also some doubt about the screw threads near PT 7.
5. Spaces between the dashes of the "dotted" lines in some cases are marginal.

PT.	NAME
1	NICKEL TUBE
2	DRIVING COIL
3	REGENERATION COIL
4	STRAIN GAUGE
5	TEST SPECIMEN
6	A.C. VACUUM TUBE VOLTMETER
7	SUSPENSION GASKET
8	SUCTION TUBE

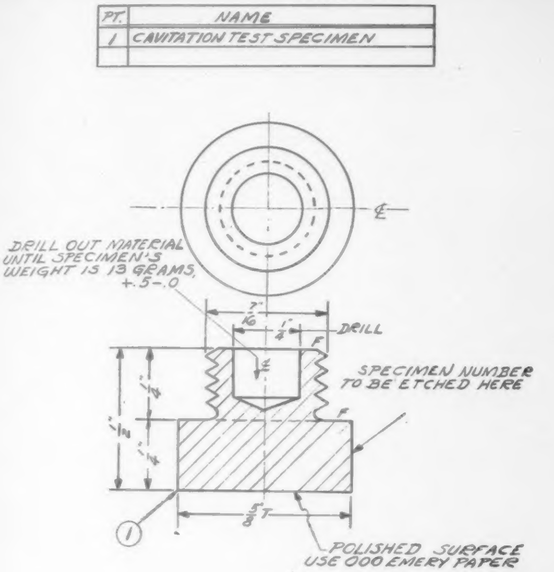


THIS WON'T DO for a good slide. As pointed out in Table II, some of the elements vital to clear slides were not properly drawn. Criticized points would be illegible, defeating the purpose of the slide. **(FIGURE 4a)**

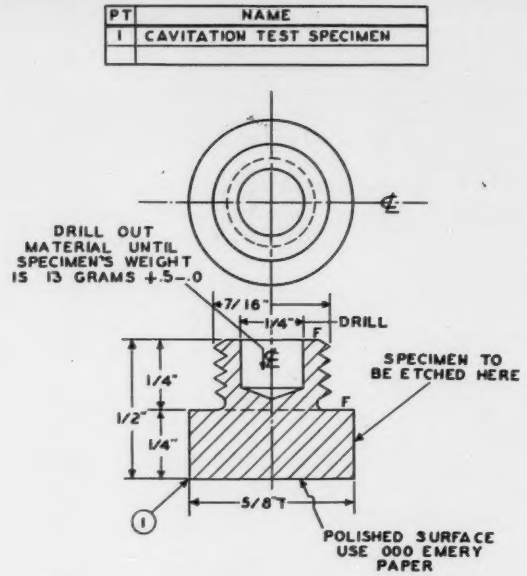
PT	NAME
1	NICKEL TUBE
2	DRIVING COIL
3	REGENERATION COIL
4	STRAIN GAUGE
5	TEST SPECIMEN
6	AC VACUUM TUBE VOLTMETER
7	SUSPENSION GASKET
8	SUCTION TUBE



SAME DRAWING REDRAWN guarantees a good, clear slide because all important details are clearly shown. This is particularly evident in the uniform spacing, size of components and legible lettering. **(FIGURE 4b)**



PART of larger drawing redrawn to increase line space and lettering size for clear slide reproduction. Letter configuration is faulty. **(FIGURE 5a)**



CORRECT LETTERING and proper and more distinct line spacing make this a suitable slide drawing. All elements are legible. **(FIGURE 5b)**

TABLE III

Departures from the set standards as found in Figure 5

1. Circular lines in the top view are not wide enough.
2. Center line is not wide enough.
3. "S"s — Top loop lines are too close together; also the top loop, of "R" in "Materials," "Number," "Paper," and "Emery."
4. "F"s indicating finishes have marginal spacing between horizontal lines.
5. Cross-section lines disappear — too thin.

of lines and letters as has been established for the screen because the drawings, the slides, and the images projected on the screen are proportional to each other by virtue of the nature of cameras and projectors. An example applied to a specific size drawing may be used to illustrate the steps involved. If the drawing paper size to be used is 8½ inches x 11 inches and the screen-distance ratio is 1/7, then

$$\frac{8.5}{d} = 1/7, \text{ or } d(\text{distance}) = 4.96 \text{ ft.}$$

At 4.96 ft.

$$\begin{aligned} x(\text{line size}) &= (.00029)\ (4.96)(12) \\ &= 0.0173 \text{ in.} \\ y(\text{letter size}) &= 7(0.0173) \\ &= 0.121 \text{ in.} \\ Z(\text{capital letter size}) &= 9.33(0.0173) \\ &= 0.162 \text{ in.} \end{aligned}$$

Figures 4 and 5 illustrate the line and letter size and the amount of information that may be presented according to the above example.

Table I is prepared in the manner illustrated above for producing slides. Figure 6 shows curves of drawing size vs. line-and-space size, and drawing size vs. distance-from-farthest-observer based on the 1 - 7 screen-distance ratio indicated herein. This curve enables one to determine the line and letter size for any size drawing or vice versa. The foregoing material applies equally well for signs, posters, charts, etc.

Once a slide has been produced from a drawing prepared by the procedure outlined, regardless of what screen-distance ratio is employed to produce the slide, it is essential that the furthest observers sit no farther from the screen than the ratio indicates for "clear" seeing. For example, when the slide is made according to the ratio of 1/7 and is projected on a screen three feet high, the farthest observer should sit no more than 21 feet away if he wishes to see clearly.

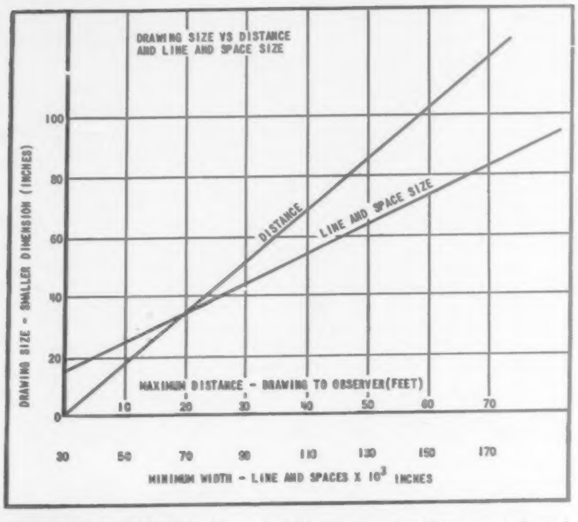
Each detail must be clear

Figures 4 and 5 have been prepared to make slides, presumably according to the standards established in Table I. Upon examination, these were found deficient in respects shown in Table II and Table III. Examination of drawings may be made with a reading glass, dividers, a scale, and a fraction-to-decimal conversion chart. Another method is to carefully make a line of the minimum size on a piece of scratch paper and compare it with all the lines on the drawing. If drawings of this type were to be made or examined often, a set of standard size lines on a transparent form would be of great assistance.

One method of producing good slides from drawings already existing for other purposes is, first, to trace all the lines important to the purpose of the slide, omitting the unnecessary ones to prevent "cluttering," then to enlarge these lines on the tracing to the proper size. If the drawing is large, it may be necessary, in order to show the required detail, to make several slides, each covering a section of the whole drawing.

Special care should be taken for spacing such as appears in section drawings where symbols for steel, iron, glass, gasket materials, etc., are used and must be distinguishable on the screen.

Figures 7 and 8 illustrate the effect fine cross-section paper may have on the contrast and how it might be avoided. Figure 7 shows the curve untouched while Figure 8 shows the



VIEWING A DRAWING by a size-distance correspondence as indicated above, an approximate means is provided for evaluating drawing for slide making as it will appear on the screen without actually making or projecting a slide. Drawing size refers to drawing and screen dimensions. **(FIGURE 6)**

result of tracing and then using ¼-inch cross-section paper under the tracing when the slide is photographed. If the black-on-white contrast cannot be attained in this manner, then compensation for it must be made in the size, brightness or both as indicated in Figure 1. Compensation must also be made, in like manner, should the brightness be sub-normal.

Summary and conclusion

The eye has been considered as an optical instrument and its resolving power has been defined. From the resolving power of the "normal" eye, equations have been developed for line and space size, lower case letter size and capital letter size by regarding the variables of brightness, exposure time, and contrast as satisfactory.

The ratio for the screen height to farthest clear-seeing observer is based upon the amount of information which may be presented according to available screen, room, and audience sizes. From this ratio and the previous equations, Table I has been prepared for line and space size, lower case letter size, capital letter size, and distance to farthest-clear-seeing observer to correspond to the recommended standard drawing sizes. In addition, a curve of drawing size vs. distance and line size has been presented for use with drawings of any dimensions.

Figures 4 and 5 indicate the amount of information which might be shown by the screen-distance ratio (1/7) and are marked for departures from the set standards.

It has been pointed out that where black-on-white contrast or normal brightness cannot be attained directly or by other means, compensation must be made in the other variables as illustrated in Figure 1.

Since practicality recommends that slides be made to suit people with normal eyesight, people with deficiencies should find a place which suits their vision best. Such compromise usually means that all viewers will get the most from slide lectures.

Using these simple rules may be a step toward standardization of drawings from which slides are to be made and may be of some value to the lecturer, engineer, draftsman, and photographer. By applying the preceding methods, optimum results and benefits are assured.

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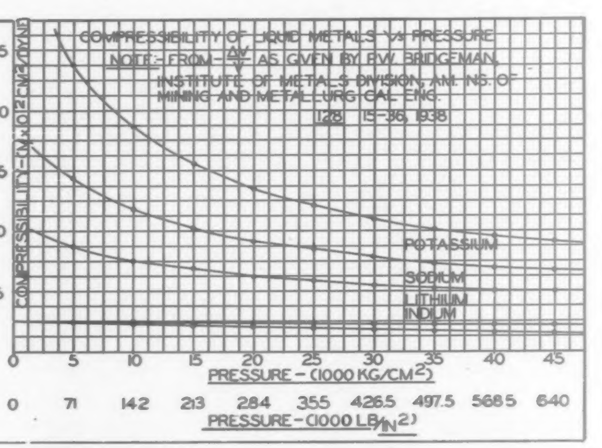
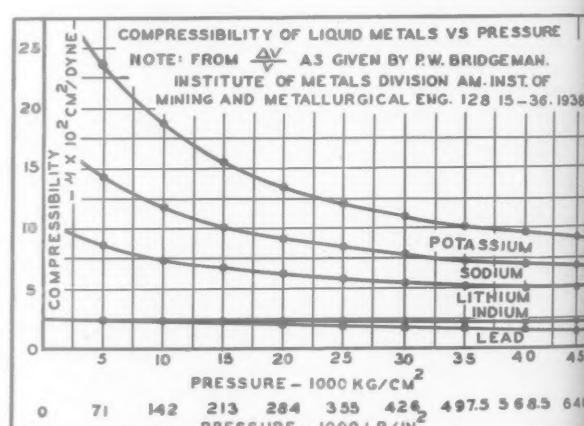


LOSS OF CONTRAST in drawing is due to the fine grid. Much clarity can be gained by pasting strips of white paper over the lettering and relettering on the clean strips to improve sought-after contrast. A considerably better solution to this is shown in Figure 8. **(FIGURE 7)**

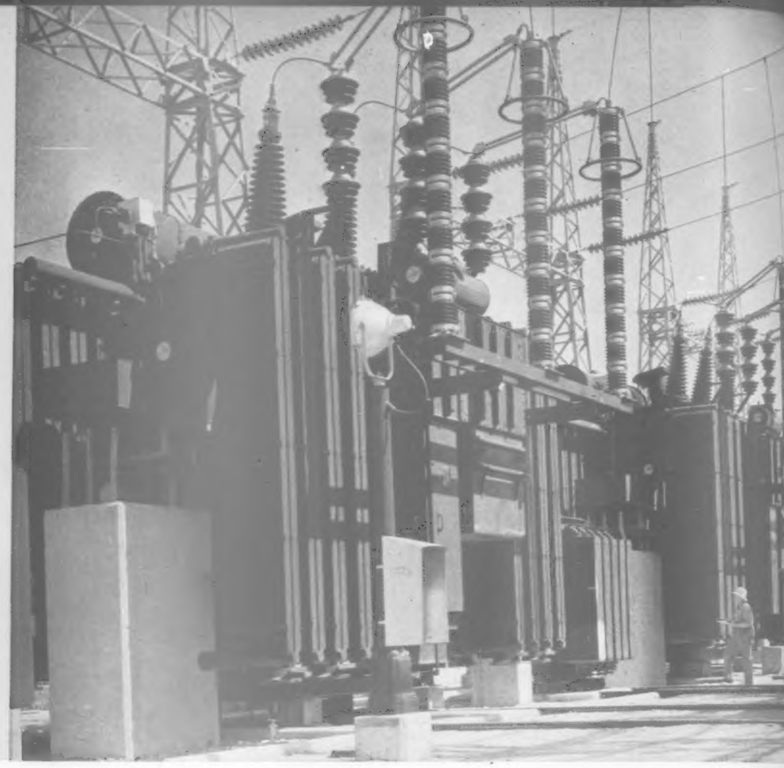


COARSER BACKGROUND GRID improves contrast. Further improvement was obtained by pasting lettering over grid marks on clean strips to provide maximum legibility. By using separate grid and tracing sheets, the original curve is intact for ordinary reproduction. **(FIGURE 8)**

LOAD CENTER UNIT substations atop the world's largest telephone manufacturing plant, recently completed, assure uninterrupted power for lighting and production needs. The six identical 500-kva (lighting) and 1000-kva (production) Chlorextol-filled units were installed in individual penthouses as shown above to save valuable production floor space. Three additional 500-kva and four 1000-kva lighting and production unit subs and a 2000-kva outdoor power unit complete the system. Tie breakers and throwover arrangements of the 16,500-kva distribution system provide for uninterrupted power flow in almost any emergency.

A-C Staff Photo

Modern LIGHTNING DIVERSION



by L. C. AICHER
Transformer Section
Allis-Chalmers Mfg. Co.

Nature of system determines which of the various types of lightning arresters is needed to protect equipment and service.

LIGHTNING ARRESTERS have become an essential component of nearly all electrical transmission and distribution systems. They assist to provide an uninterrupted supply of power to the consumer, and help protect the utility's investment against damage in territories where the records show lightning is prevalent.

On an unprotected system lightning potentials can cause flashovers leading to short circuits followed by circuit breaker or fuse operation that interrupts power flow. These potentials may cause permanent damage to apparatus, necessitating either repairs or replacements. Such interruptions often result in considerable inconvenience and sometimes financial loss to the electricity user.

As lightning strikes a conductor, it suddenly dumps a large quantity of energy into the circuit. The migration of this energy is the cause of the potentials which are dangerous to insulation. The voltage (between four and five million volts have been recorded on 132-kv transmission lines) depends on the current and impedance of the circuit through which the current travels. Insulation flashover depends upon the rate of increase of voltage with time.

Even though man does not know how to prevent lightning, there is no economic justification for building equipment to withstand the highest known lightning potentials. Instead, methods are used that protect the system and its functions from flashovers or damage.

Ground wires provide basic protection

Overhead ground wires lessen the possibility of extreme voltages for they intercept direct strokes, keeping them off the conductor. They also distribute the transient current into two or more paths, thereby reducing the voltage drop. A third and minor function of the overhead ground wire is to protect against induced voltages from nearby strokes by increasing the capacitance between conductors and ground which reduces the voltage from conductor to ground.

A measure of the effectiveness of overhead ground wires is the protective ratio, defined as the ratio of the voltage on a conductor with ground wire protection to the voltage which would exist on the conductor without ground wire protection. Protective ratios of the order of 0.10 are possible. The voltages produced are proportional to the height of the transmission line conductor, the crest of the current in the stroke to ground and the distance of the conductor from the stroke channel. Induced voltages of sufficient magnitude to produce flashover occur so infrequently as to be of little importance, except possibly on lines of very low insulation strength.

The effect of direct strokes on the transmission system is of a greater concern. A direct stroke produces a wave of voltage travelling in either direction from the stricken point. A travelling wave induces an accompanying wave on adjacent isolated conductors.

When a direct stroke occurs, the voltage across the insulation is reduced by coupling between the conductors and the overhead ground wires. This coupling is greater in proportion to the number of ground wires and the distance between them and the conductors. The spacing between ground wires and

conductors, however, should be great enough to prevent flashover at mid-span.

It has been found that a ground wire will protect a solid angle under that wire. Experience has shown that double circuit lines will be shielded if two ground wires are placed one above each outermost conductor at a height above the top conductors equal to the vertical spacing between conductors. For a horizontally arranged single circuit line, two overhead ground wires will give good shielding if placed a height above the plane of the conductors equal to two-thirds the spacing between conductors and spaced horizontally a distance about equal to the spacing of the conductors.

If the station is shielded from direct strokes and has low ground resistance, the only remaining source of lightning voltage is from travelling waves coming in on the conductors. If the line conductors in turn are adequately shielded from direct strokes by ground wires, then the source of travelling waves is usually a flashover of the insulators and the voltage is limited to the insulator flashover value. This is generally in excess of the basic impulse insulation level of the station apparatus and must be brought below this level by other means.

Lightning arresters divert lightning

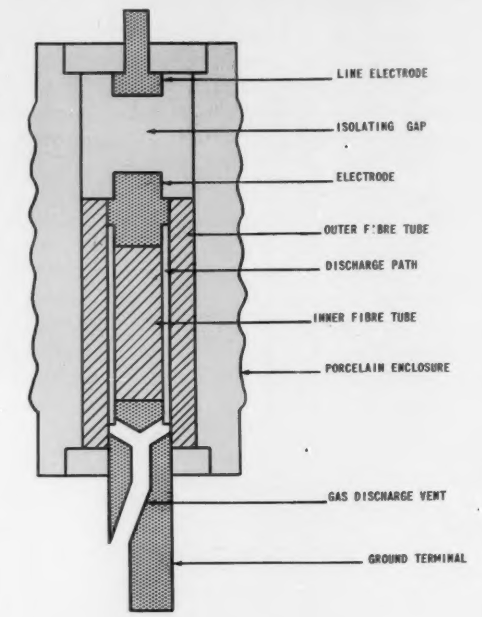
Man has long used the simple lightning rod as a means of directing lightning currents to ground through a path of low resistance and controlled direction. Lightning rods are used on electric system towers and poles, with or without overhead ground wires. Such a lightning rod cannot be attached to the system conductors for, although it would limit the voltages on the conductor, it would act as a permanent short-circuit on the system. One expedient is a simple spark gap such as the gap between two rods or spheres set to flash over at a predetermined voltage level and used to limit the voltage on the conductor. However, if such a gap is used, and if it accomplishes its function, it is quite likely that 60-cycle power would follow the lightning sparkover, resulting in a power follow current which the gap could not interrupt. It would then be necessary to de-energize the system with a circuit breaker or a fuse to interrupt this current.

A lightning arrester combines the functions of a lightning rod, a spark gap, and a current interrupter. It grounds the system momentarily during the surge, then interrupts the follow current. Why this device is called a lightning arrester is not quite clear, for it actually is a lightning diverter and power follow arrester.

Lightning voltages can rise at the rate of hundreds of thousands of volts per microsecond. This requires a switching mechanism in the form of a spark gap. It is designed to provide insulation at normal system voltages but, when the lightning voltage occurs, the gap sparks at a predetermined value and establishes a path for the lightning current and subsequent power follow current. The power follow current must be interrupted quickly however, so a vital element of a lightning arrester is a device in series with the spark gap that either interrupts the follow current or aids the gap to interrupt it. This is accomplished by either of two ways resulting in two arrester types, the expulsion arrester and the valve arrester.

Expulsion arrester interrupts follow current

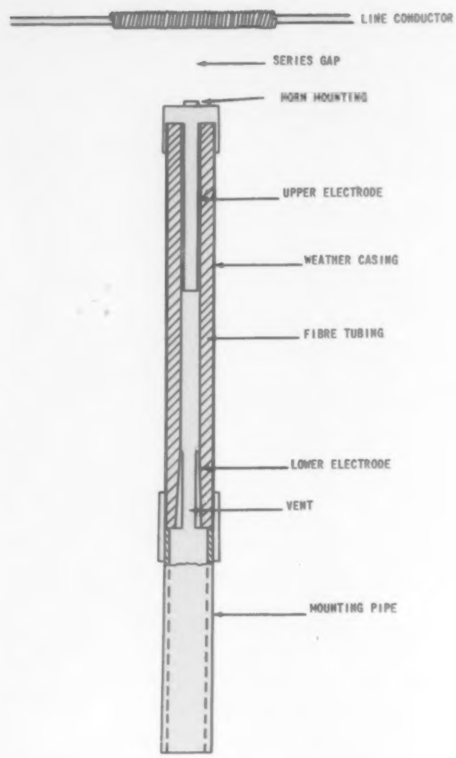
The expulsion arrester consists of an external gap in series with a second gap inside a fiber tube, as shown in Figure 1. When a lightning voltage appears both gaps flash over, establishing a current path. The impedance of this path is extremely low so a momentary short-circuit exists on the system. The arc through the gap in the tube causes gas to be expelled from the walls of the fiber tube. This gas is an ionized mixture of water vapor, absorbed in the fiber, and hydrocarbon gases resulting from the volatilization of minute portions of the fiber. This mixes with the ionized air in the arc path and promotes de-ionization. As the power follow current wave passes through instantaneous zero, the arc de-ionizes rapidly restoring the insulation strength of the gap and interrupting the power follow current. The power follow current in an expulsion arrester can be of considerable magnitude, but its duration not more than one or two half cycles. Thus, no disturbance is noticeable on the system.



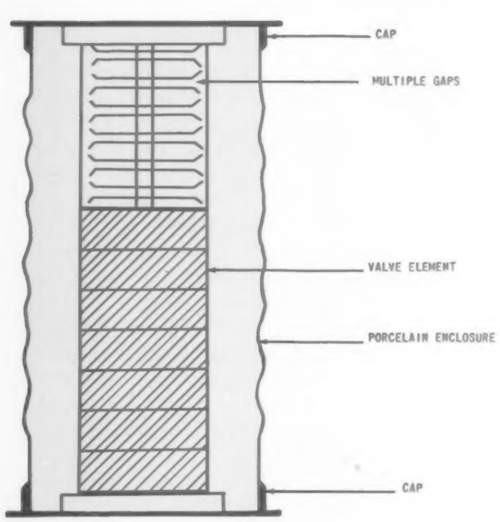
CROSS SECTION SKETCH illustrating the functional elements of the expulsion type lightning arrester. **(FIGURE 1)**

Although the interrupting chamber incorporates a spark gap it is not connected directly to the system because constant voltage on the fiber eventually causes tracking and carbonization. The external series gap is used to prevent this action. Surge discharges with a few cycles of power current do not produce carbonization but leave the fiber walls very clean. The expulsion arrester operates repeatedly without attention. It has good life and is economical.

The simplest lightning arrester in practical use is a type of expulsion arrester used to protect transmission line insulation against flashover where overhead ground wires are not used or where they are not sufficiently effective or economical. It is called a protector tube, Figure 2. It is mounted so as to shunt the insulators it is to protect. The external gap is made by leaving a space between the electrode in the end of the



FUNCTIONAL ELEMENTS of the transmission line protector tube are shown above. **(FIGURE 2)**



VALVE TYPE ARRESTERS provide excellent surge voltage limitation for application above 15,000 volts. **(FIGURE 3)**

fiber tube and the line conductor. The top of the tube may have a shape that maintains a reasonably constant length of gap when the conductor swings in the wind. The flashover value of the insulation in shunt with the tube must be higher than the spark-over value of the tube. In the transmission line type, the 60-cycle voltage against which the arrester will interrupt power follow current is determined principally by the length of the gap in the arc chamber. This in turn usually fixes the impulse sparkover, as the external gap has little effect.

The current interrupting ability must be equal to the fault current of the system for a fault at the tube location. Since fault currents vary over wide limits depending on the system voltage, kva and impedances, it is usually impractical to make a single expulsion arrester to handle all magnitudes of fault current that may be encountered. Therefore, these arresters have maximum and minimum 60-cycle current levels. If the arrester is applied where the fault current exceeds the maximum limit, the tube may burst from the high gas pressure. If the follow current is less than the minimum limit, not enough gas is expelled to extinguish the power follow arc. It is, therefore, very important to apply the proper rating of expulsion arrester at each location.

The transmission line arrester must be simple and it must be low in cost to compete with the overhead ground wire. The arrester has one advantage over the ground wire. Its effectiveness is not handicapped by high ground resistance. The arrester and insulation are in parallel so that at any arrester location the ground is external to the protective circuits. On the other hand, the ground wire system is a simple mechanical device and where its cost is reasonable it is usually preferred.

Valve arrester limits surge voltage

The valve arrester shown in Figure 3 performs the same function as the expulsion unit though its operating elements are different. The series gap usually provides insulation and must flash over to close the circuit when the need arises. This gap must also reopen the circuit by interrupting the power follow current when the surge has passed. The gaps consist of a series of short spaces between curved metallic electrodes, resulting in a gap with excellent impulse breakdown characteristics. It cannot, however, interrupt high power follow current, so it is necessary to limit the magnitude of the current to that which the gap can interrupt by a series resistance.

The voltage drop across a linear resistor when carrying high lightning current would be so high that the arrester would provide no protection. Therefore, the resistance used in valve type arresters has a non-linear characteristic that maintains a nearly constant voltage drop across the elements. The voltage across this resistor does not vary directly with the current, but instead as a fractional power of the current. When the normal system voltage is applied the current is small because the apparent resistance is high. During the discharge of a high surge current, the apparent resistance is low and the voltage remains relatively low. This variable resistance device passes lightning current without permitting high voltage, yet limits power follow currents to a value the gap can interrupt.

The resistance, referred to as the valve element, consists of many small crystals of silicon carbide. The unusual characteristics of these elements reside in the phenomena that take

place at the contacts between the particles. Relatively little is known about the phenomena producing this non-linear resistance.

Apparatus protection on circuits of higher than 15,000 volts is pretty well restricted to valve type arresters. Expulsion arresters are not used because their impulse sparkover voltages are higher than those of valve arresters of the same rating. In the range of distribution voltages this is not of consequence because the margin is large between the sparkover potential of the expulsion arrester and the impulse voltage that the apparatus will withstand. In the higher voltage applications the ratio between the basic impulse insulation level of the apparatus and the operating voltage is less than in distribution apparatus, requiring greater relative limitation of surge voltages. Valve arresters accomplish this limitation.

Valve arresters vary in type and use

The term "station arrester" denotes a type of arrester and class of arrester performance. Station type arresters are the most effective and most durable. They are capable of discharging current surges of 100,000 amperes without damage.

The series gap structure consists of a multiplicity of short gaps that make a compact totally enclosed arrangement possible, with good impulse sparkover characteristics and good power follow extinguishing ability. The enclosure eliminates effects of weather. Each gap is shunted by high resistance to insure good 60-cycle voltage distribution and to provide some heat to keep the structure dry. Each gap is equipped with a small pre-ionizing device that insures low and consistent impulse sparkover.

Station type arresters are built in units, each unit being a complete arrester. Low voltage arresters may consist of only one unit and higher voltage arresters of a number of units bolted together.

When "line type arresters" were first developed they were intended for the protection of transformer banks located "out on the line." Again this type of arrester identifies a class of performance. It is smaller, and lower in cost than the station arrester. Its series gap structure is almost identical with that of the station arrester, but the valve element is smaller in cross section and volume, making the whole arrester smaller in diameter and lighter in weight. The surge voltages are slightly higher and surge current withstand ability is less (65,000 amperes) than in station arresters. Line type arresters are also built in sections that can be bolted together to form units of various ratings.

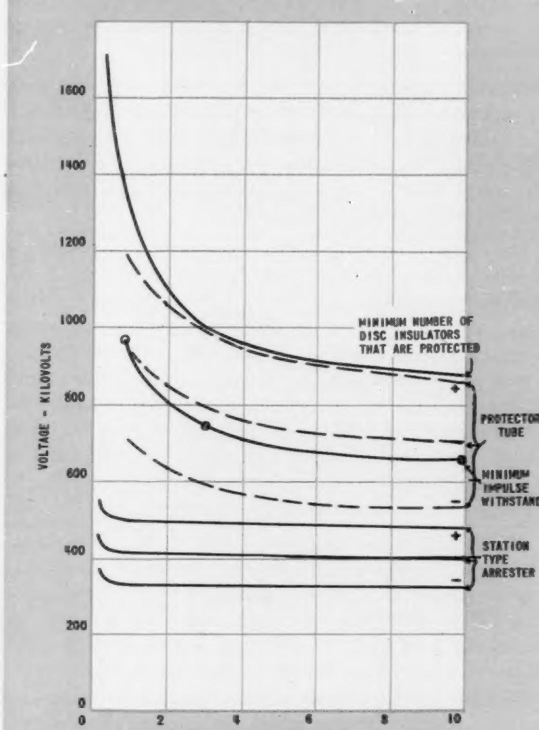
Usually, distribution equipment is considered as that connected to circuits of 2400 to not more than 15,000 volts. This is not a rigid definition because there are circuits of these voltages that are power circuits, however, arresters used with apparatus at these voltages are generally termed "distribution arresters." They are small, relatively inexpensive devices used in large quantities on distribution systems.

Distribution arresters are of both the expulsion and valve types. The expulsion type is of more elaborate construction than those used for transmission line protection, because of more rigid requirements. Their impulse sparkover voltages must be sufficiently low to provide ample margin with respect to the insulation levels of distribution apparatus. Their 60-cycle current interrupting capacity is as wide as possible because the fault currents of distribution systems, considered as a whole, vary over wide ranges and users do not want to be bothered either with numerous ratings of distribution arrester or with designated zones of applications for these ratings. It is not economical to devote much engineering time to the application of distribution arresters. Distribution arresters in general use (Figure 4) have impulse characteristics that provide ample protection and in most cases are built to be applicable practically anywhere on any system.

Valve type distribution arresters differ from station type of line type arresters largely as to performance. Their mechanical structure is somewhat different in that usually the resistive element consists of loose granules of silicon carbide closely packed in a chamber, although some types use other shapes of resistive material. The resistive elements in the larger station and distribution type units are in the form of blocks of silicon carbide that are assembled inside the insulating column.

Arrester application

Where the highest degree of protection is desired, station arresters are preferred, and where smaller equipment is to be protected the line type arrester is used, as the cost of the station arrester cannot be warranted. Most systems apply line type



VOLT-TIME CURVES of 138-kv system suspension insulators, protector tubes, transformer insulation, and station type lightning arrester levels and tolerances are shown above. (FIGURE 4)

arresters on 23 to 69 kv. Below 23 kv a distribution type arrester is usually used while a station type unit is preferred above 69 kv. Departures from these general applications are justified by the investment in the equipment that is to be protected.

The rating of a device is an indication of its operating limits. The rating implies that if the device is used beyond its rating it will not perform as expected and will likely be damaged. Lightning arresters are voltage sensitive devices. All alternating current arresters have a voltage rating expressed in terms of 60-cycle rms voltage. This is a maximum rating and designates the highest 60-cycle voltage against which the arrester can interrupt power follow current and revert to its insulating condition following a discharge. This rating must be respected for the sake of safety to the arrester.

As arresters are usually applied from line to ground, it follows that the arrester is influenced more by the 60-cycle voltage from line-to-ground than that between phases. It is desirable to make a study of system characteristics to determine the voltages that can occur from phase-to-ground during abnormal conditions. Usually, arresters are applied with their maximum 60-cycle voltage equal to not less than 105 percent of the phase-to-ground voltage expected during fault conditions. There are some systems where this margin must be larger in order to avoid excessive arrester failures. If the phase to neutral voltage is low during faults, it is reasonable to use correspondingly lower arrester ratings as they will permit lower impulse voltages and lower costs.

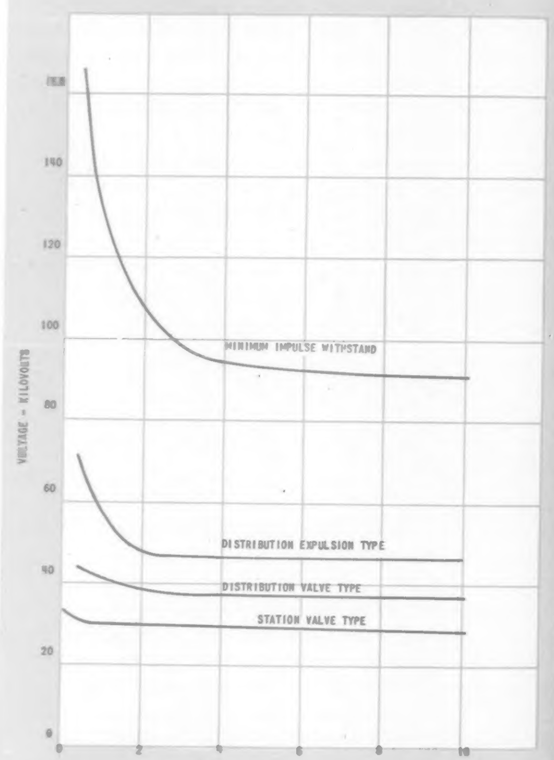
Expulsion arresters which require limitations on the power follow current are rated in 60-cycle amperes as well as volts. The current rating is often called fault current rating because it is given in terms of symmetrical 60-cycle short-circuit current that would occur at the arrester location if the arrester were short-circuited by a solid conductor.

The higher the voltage rating of an arrester, the higher its impulse characteristics. In most types there is a fixed ratio between the arrester voltage rating and the impulse characteristics. Arrester operation occurs within a band of voltages rather than according to a distinct line. This is shown in Figure 5. The band includes tolerances from a mean value to allow for manufacturing and testing variations. Arrester protection can only be relied upon when the limit of these tolerances is recognized. Tolerances may amount to $\pm$ 25 percent for gap sparkover and $\pm$ 20 percent for IR drop, depending on the type of arrester and its class of performance.

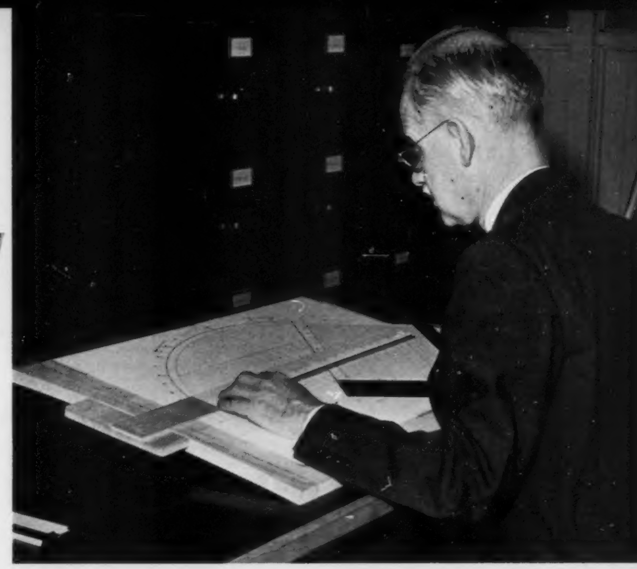
The basic impulse insulation levels of modern apparatus have been set largely on the basis of the protective levels available in modern station type lightning arresters. Arresters are connected in shunt with the insulation they are to protect and they should be close to the apparatus and the leads should be short. They each have inductance and the rapidly changing lightning discharge currents produce undesired voltage drops in series with the voltage across the arrester. Furthermore, travelling wave effects on conductors result in higher voltages existing at points remote from the arrester than those appearing at the arrester terminals. The impulse characteristics of arresters are measured at their terminals, extraneous effects of lead lengths or resistances increase these voltages at the location of the protected apparatus.

There may be cases such as on very old apparatus having impulse levels that are considerably lower than modern equipment where coordination is not achieved in the usual manner. In such cases it may be advisable to select an arrester with a lower rating that provides protection for the equipment but involves a known and recognized risk of damage to the arrester. Another choice to insure the highest degree of freedom from service outage and equipment damage is to re-insulate such old apparatus or replace it with modern apparatus. Sometimes it is more economical to sacrifice a lightning arrester than to damage a large piece of equipment like a transformer.

Lightning arresters are designed to be economical and practical for the conditions they are intended to meet. They are meant to operate for a short period of time only. All but a small portion of an arrester's life is spent in idleness. The reliability of modern lightning arresters is beginning to exert a significant effect on the insulation levels of high voltage equipment. Savings in insulation and, therefore, in equipment cost can be realized as a result of the protective levels that can be maintained by modern arresters. This has been accomplished in some instances in the past and with today's economic trend it is receiving greater study.



VOLT-TIME CURVES of 11,500-volt distribution system transformer insulation, expulsion and valve type distribution arresters, and station type arrester levels. Tolerances are not shown. (**FIGURE 5**)



FOR DISTRIBUTION ENGINEERS

by **J. B. HODTUM**
Allis-Chalmers Mfg. Co.
Pittsburgh, Pa.

Easy-to-make, easy-to-use "ouija" board provides quick regulation and power factor answers for transformers and lines.

YOU CAN SAVE HOURS and reams of paper by using this simple calculating board to determine regulation of transformers, lines, and similar electrical equipment. It's easy to make, requiring only a few tools and a few hours of time. All of the steps in construction are described.

Using the board

A transformer having a 0.5 percent resistance and 6.0 percent reactance rating is supplying an 80 percent lagging power factor load. Determine the transformer regulation.

Set the arrow on the impedance scale at 80 percent lagging power factor. Move the T-square to a point on the impedance scale where the percent resistance is 0.5 and percent reactance is 6.0 and read the percent regulation on the regulation scale. The answer is 4.10 percent regulation for the transformer.

The board also provides an easy means of speeding the job of determining line regulation.

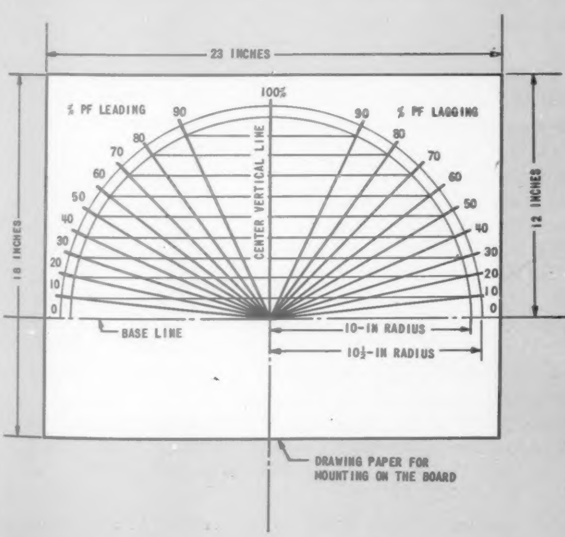
With No. 4 copper conductors symmetrically spaced at 30 inches at 13,800 volts for a ten mile run and carrying 1,000 kva at 90 percent power factor, determine the line regulation.

Line resistance and reactance must first be obtained from tables that are generally available.

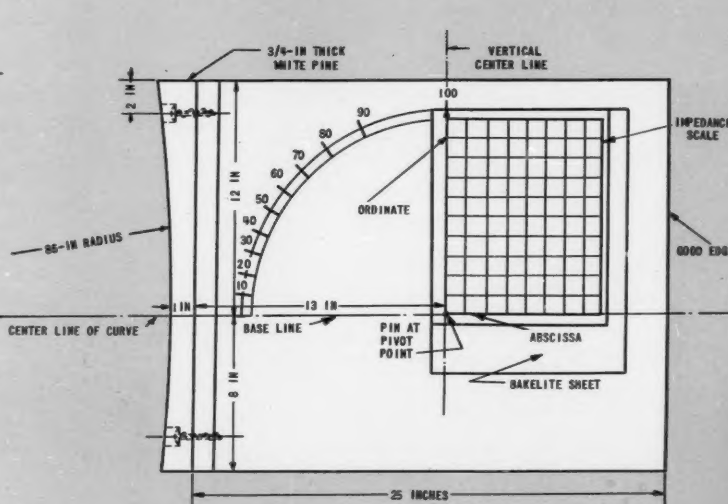
Line resistance = 1.41 ohms per mile at 25 degrees centigrade

Line reactance = .713 ohms per mile

$$\%r = \frac{\text{current} \times \text{resistance}}{\text{voltage}} \times 100$$



POWER FACTOR SCALE can be constructed quickly and accurately by following this simple graphical method. **(FIGURE 1)**



BOARD IS ASSEMBLED so that the impedance scale is free to pivot on the center of the power factor scale. **(FIGURE 2)**

Doing it the Hard Way...

The answer to the transformer regulation problem on page 15 can be obtained the hard way with either the exact or the approximate formulas of section C 57.22.076 of the American Standards Association.

A. Exact formulas for the calculation of regulation

(1) When the load PF is lagging,

$$\text{Regulation} = \sqrt{(r+p)^2 + (x+q)^2} - 1$$

(2) When the load PF is leading,

$$\text{Regulation} = \sqrt{(r+p)^2 + (x-q)^2} - 1$$

B. Approximate formulas for the calculation of regulation.

(3) When the load PF is lagging,

$$\text{Regulation} = pr + qx + \frac{(px - qr)^2}{2}$$

(4) When the load PF is leading,

$$\text{Regulation} = pr - qx + \frac{(px + qr)^2}{2}$$

In the above formulas:

p = power factor

q = reactive factor of the load

r = resistance factor of the transformer or system

x = reactive factor of the transformer or system

$$q = \sqrt{1 - p^2}$$

$$r = \frac{\text{current} \times \text{reactance}}{\text{voltage}}$$

$$x = \frac{\text{current} \times \text{resistance}}{\text{voltage}}$$

The quantities p, q, r, and x are on a per unit basis so that the results must be multiplied by 100 to get regulation in percent.

With the exact formula and the same problem

$r = 0.5\%$ or 0.005 units

$x = 6.0\%$ or 0.060 units

$P = .8$

$q = .6$

Substituting these values in (1)

$$\text{Regulation} = \sqrt{(.005 + .8)^2 + (.06 + .6)^2} - 1$$
$$= 1.04097 - 1 = 0.04097 \text{ units}$$
$$4.097 \text{ percent}$$

Substituting in the approximate formula (3)

$$\text{Regulation} = (0.8 \times .005) + (.6 \times .06) + \frac{(.8 \times .06 - .6 \times .005)^2}{2}$$
$$= 0.04 + 0.001012 = 0.04102 \text{ units}$$
$$= 4.102 \text{ percent}$$

Note that, with either of the above methods, accuracy required precludes the use of a slide rule.

$$\%r = \left[\frac{1{,}000{,}000}{13{,}800 \times \sqrt{3}} \times 14.1\right] \div \left[\frac{13{,}800}{\sqrt{3} \times 100}\right]$$
$$= 7.4\%$$

$$\%x = \frac{\text{current} \times \text{reactance}}{\text{voltage}} \times 100$$
$$= \left[\frac{1{,}000{,}000}{13{,}800\sqrt{3}} \times 7.13\right] \div \left[\frac{13{,}800}{\sqrt{3} \times 100}\right]$$
$$= 3.75\%$$

Set the impedance scale at 90 percent lagging power factor, move the T-square to a point on the impedance scale where percent r equals 7.4 and percent x equals 3.75 and read the regulation. The answer is 8.3 percent line regulation.

Also shows pf correction needed

The board can be used to determine the load power factor required to limit the regulation of a transformer or line to some given value. If in the above case 8.3 percent regulation is too high and it is desired to limit this to two percent, the impedance scale is rotated and the T-square moved until the point on the impedance scale where r is 7.4 percent and x is 3.75 percent coincides with two percent regulation on the regulation scale. Reading the percent power factor on the scale, a 62.0 percent leading power factor load would be required to obtain two percent regulation on the lines.

Thus enough corrective capacity would have to be added, at the load, to change the load power factor from 90 percent lagging to 62 percent leading.

Now make your own

A 20 by 25 by ¾-inch drawing board was purchased at the stationery counter in a large department store ($3.29). A ¾-inch thick strip with one edge cut to an 86-inch radius was machined out of white pine. For convenience the main base line along which the radius was measured was eight inches from bottom end and twelve inches from the top. The strip was trimmed to a one-inch width at this base line point.

The board had only one good machined edge for use with a T-square. The strip was drilled, countersunk and screwed onto the edge of the board opposite the good edge. Screw holes were then filled with wood plastic filler.

The T-square (69c) was carefully cut off so that the ends of the running edge are equidistant from the ruling edge. This was done so the ruling edge becomes an extension of the radius of the curved edge when the corners of the running edge of the T-square are against the curve.

A 180-degree arc with a 10-inch radius was inked in on a sheet of drawing paper 23 x 18 inches as shown in Figure 1. The base line of the arc was drawn 12 inches down from the top of the paper. A line at right angles to the base line extending from the center of the base line to the arc was divided into ten one-inch divisions. Lines were drawn parallel to the base line through these division marks and intersecting the arc at both ends. Another 180-degree arc but with a 10½-inch radius was drawn about the same center and with the same base line. Lines were drawn from the center through the intersecting points on the 10-inch arc extending out to the 10½-inch arc. The intersecting points on the 10½-inch semi-circle correspond to the cosine of the angles between the center vertical line and lines through the 10½-inch radius arc. The intersecting point on the outer arc of this center vertical line corresponds to 100-percent power factor. The 10 intersecting points on each half of the outer arc were then labeled from

FIRST OUTDOOR HYDRO PLANT to be remotely controlled from a distance of three miles utilizes a subterranean river for power generation. Telemetered indications at a down-river station report operating conditions. Only man at plant is a watchman who makes two daily inspections.

100 percent at the center to zero at the base line and in each direction from the 100-percent power factor point. Angles at the left of the 100-percent point represent leading power factor and those to the right, lagging power factor. If desired, intermediate power factors value can be added by further subdividing the vertical center line.

This sheet of drawing paper was attached to the board with the center point of the arcs exactly 14 inches from the curved edge of the board measured along the base line as shown in Figure 2. A 1/16-inch hole about ½ inch deep was drilled in the board through the exact center point of the arcs on the base line.

Standard 20-line-per-inch graph paper was rubber-cemented to a 10 by 13 by 1/32-inch sheet of canvas base bakelite. Scale values were marked on the graph paper with zero at the lower lefthand corner along the ordinate and abscissa with one unit to an inch. The units along the ordinate axis are percent reactance and those along the abscissa are percent resistance. An arrow was marked on the edge of the graph paper at the upper end of the percent reactance scale. This chart forms the impedance scale. A very small hole was drilled through the zero point. A wire nail 1/16 inch in diameter cut approximately ½ inch long was used as the axis on which the impedance scale rotates.

Another strip of the same type graph paper was rubber cemented adjacent to the edge of the T-square with the zero point at the exact pin center. This forms the regulation scale. Care was taken to see that at the 100-percent power factor setting lines on the T-square lined up with those on the bakelite when the T-square is at the zero point. This care assures accurate readings. The graph paper on the T-square is marked in units per inch and in both directions from zero. After completing this simple assembly the board is ready to use.

Your construction may be checked by Figure 3. The design principle of the board is shown in Figure 4.

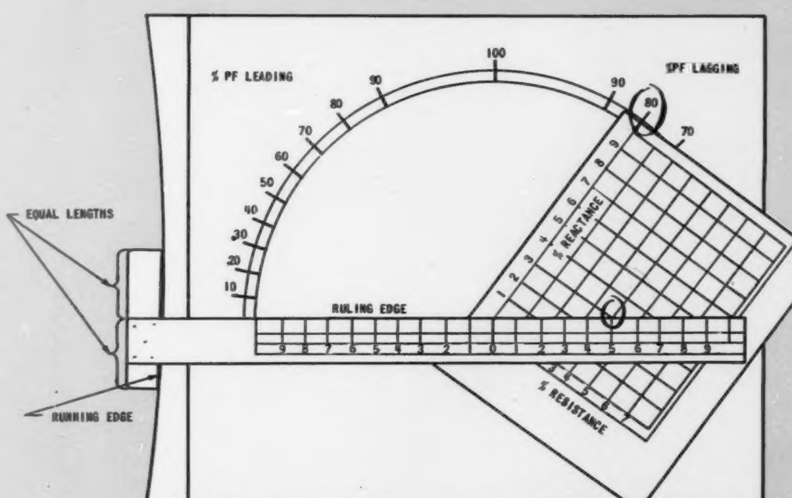
By turning the board over it remains a handy drafting board and the T-Square may still be used as a T-square on the good edge of the board.

Many variations in construction

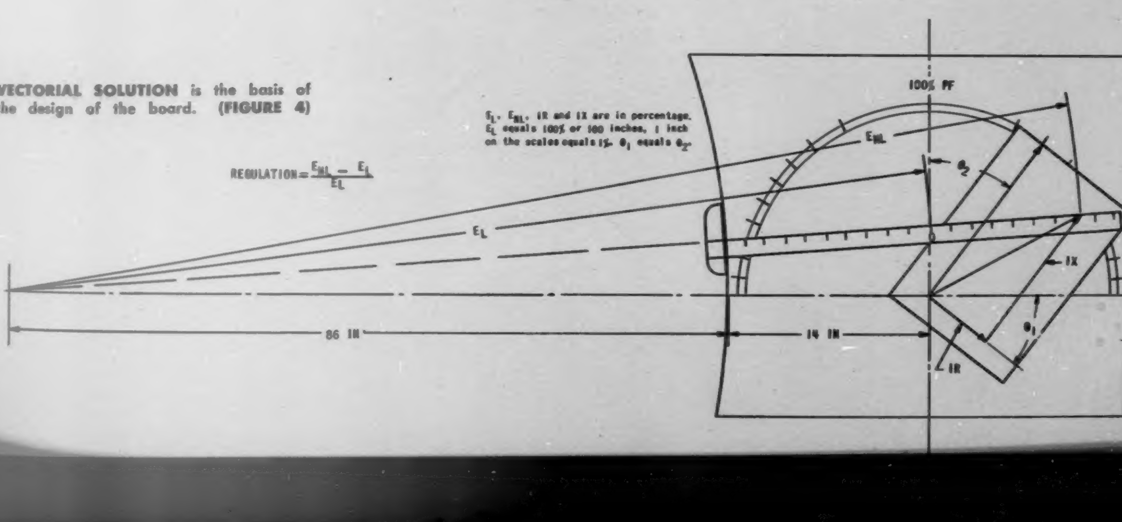
The board need not be the same size and may be any board that's large enough to allow the pivoting of the impedance scale. The T-square may be a different length but head must be cut off so that the ends of the running edge are equally distant from the ruling edge. By beveling the ruling edge of the T-square so that the graph paper on the T-square will be close to that on the board, parallax will be minimized and accurate reading will be much easier. The wooden strip was machined in a pattern shop but can be cut out with a home workshop band or jig saw and sanded to make a smooth sliding surface. Other wood could be used but white pine is readily available and has little grain.

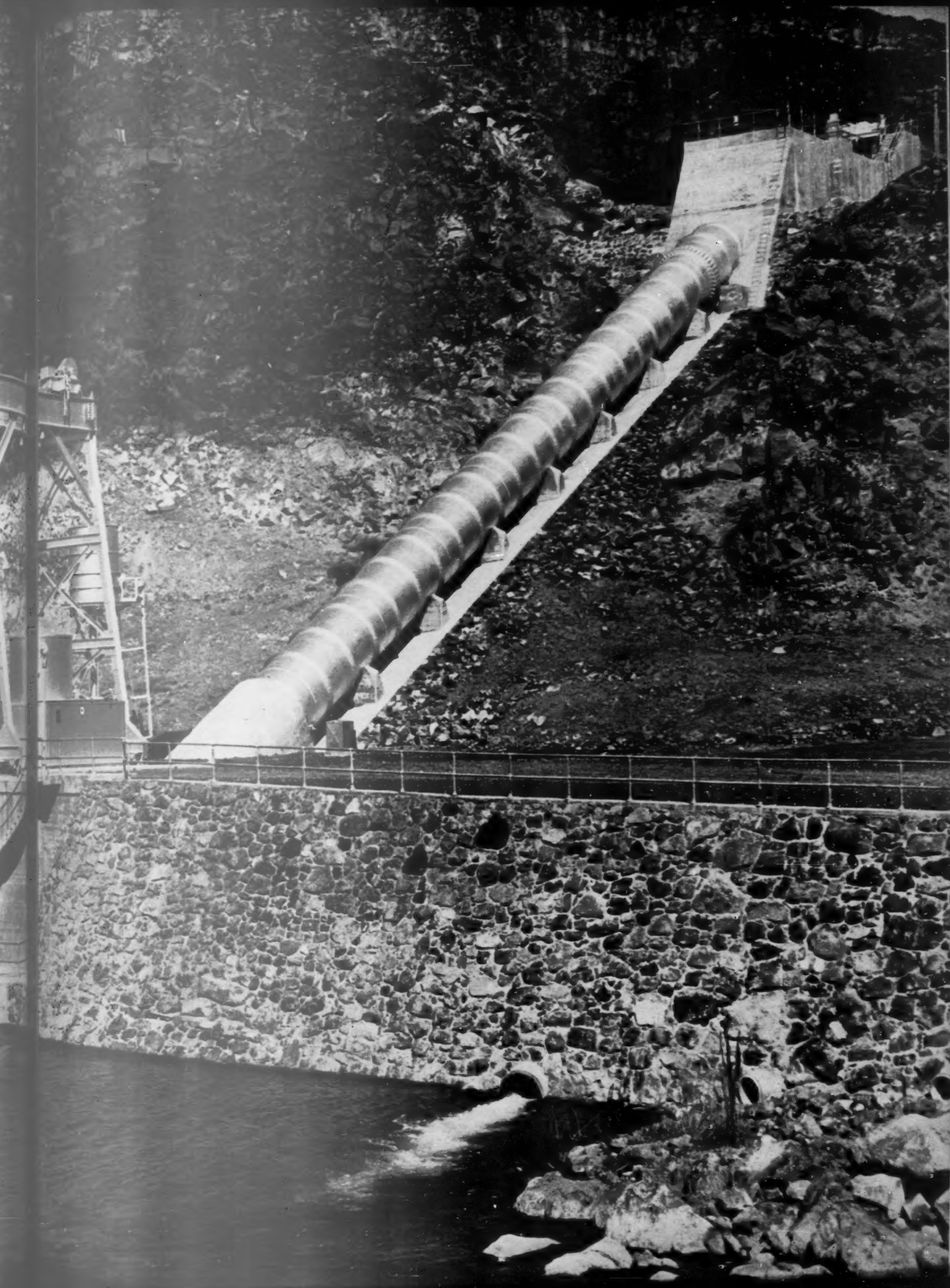
A substitute for the bakelite sheet could be made of plastic, pressed wood, or various other materials, but should not be made of material that will warp.

CHECK YOUR BOARD. With three percent reactance, four percent resistance and 80 percent power factor, the regulation is five percent. Regulation on the right of zero is positive and on the left negative. **(FIG. 3)**



VECTORIAL SOLUTION is the basis of the design of the board. **(FIGURE 4)**





Basic Rules FOR PROTECTIVE RELAYING

Ready-reference charts and fundamentals of metal-clad switchgear relaying equipment are presented in brief and concise form.

by H. V. NYE
Switchgear Section
Allis-Chalmers Mfg. Co.

THE ESSENTIAL PRINCIPLES underlying the most common protective schemes used in connection with metal-clad switchgear provide simple and effective line, load and equipment protection to meet basic standard needs. These recommended schemes form a ready reference for engineers who are required to consider the problem of relay protection only occasionally. An analysis of the entire field of relay protection would be too complicated and involved for such a purpose.

The application of protective relays in general has two objectives:

1. To protect the apparatus connected to the circuit from damage through overloading, or other cause, and to limit the damage as much as possible in case of a fault developing in the apparatus itself.
2. To provide continuity of service on as much of the system as possible when it is necessary to isolate certain equipment or circuits due to actual faults on such circuits.

If an insulation failure, or short circuit from any reason, occurs anywhere in the electrical system, it is vitally important that the disturbance on the rest of the system should be minimized. This is done by applying protective relays at any given location so as to isolate the point where the fault occurs, and keep the rest of the system operating normally.

The extent to which this can be realized in practice depends on such factors as location, cost of protection, and importance of the line or apparatus affected. Some circuits will justify much greater expense for relaying than the less important ones.

Obtain and follow utility advice

This problem of relay protection is broadly a question of coordinated engineering on the system as a whole. The relay equipment required on any metal-clad switchgear installation depends to some extent on the relay protection employed on the lines outside the switchgear installation. Consequently, in cases where the switchgear installation connects to the lines of a public utility, it is necessary to consult with the power company engineers and obtain their recommendations as to the types of protection required to properly coordinate with the line and system protection employed by the utility.

On metal-clad switchgear the relay protection provided is usually concerned with the circuits and apparatus in the station itself and varies according to the apparatus connected to each circuit. Normally, this consists of one or more generators, motors, transformers, circuit breakers, and buses and their connections.

Each of these elements of a circuit is subject to damage from one or more of several abnormal conditions which may occur in operation and for which protection can be provided to prevent or greatly limit the damage that could result if the abnormal condition was allowed to continue. The conditions which may exist and for which protection is usually provided include:

1. Overload or overheating
2. Overcurrents due to failures or faults
3. Overvoltage or undervoltage
4. Overspeed
5. Mechanical failure not associated with electrical failure.

Unattended stations need maximum protection

The character of protection provided in an attended station varies in many respects from that desirable in one that is unattended. In an attended station the operator can determine what action is justified under a given condition, provided that the time required for him to exercise this judgment and to take the necessary action will not greatly jeopardize the equipment or extent of damage. In such cases protection consists largely in making sure that the operator will be made aware of potentially dangerous conditions.

In case of short circuits or overcurrents exceeding the capacity of the apparatus to carry for any extended period it is necessary in all instances to provide relay operation which will trip the circuit breakers serving the affected circuits. Thus actual fault protection varies very little between attended and unattended stations.

In unattended stations any real protection provided must, in general, be automatic and result in the prompt removal from service of any equipment in trouble from any cause. Generally, it is not feasible to rely on getting an attendant to the station in time to correct any dangerous condition. Consequently, unattended stations usually require more complete relay protection than do attended stations.

Table I lists some of the most usual types of protection furnished for standard types of metal-clad switchgear. The table

shows which types are specified for standard NEMA units and which are applicable and available when required. This is by no means a complete listing of protection measures available, but this information on the most commonly used protection schemes provides a ready reference for those only occasionally considering protection problems. Ground relaying or line protection beyond the circuits controlled by the switchgear equipment are also not included.

Pick relay for the job

Before selecting a particular protective relay scheme it is well to remember that circuit breakers are the protective device on which all relay protection is based. Consequently it is vitally important that the circuit breaker selected will be able to interrupt the maximum short circuit which can occur at the point it is applied and withstand any through current to which it may be subjected. When properly selected it will then act through the functioning of the protective relays to protect the circuits in which they are located and the apparatus connected thereto. The various types of protection to be discussed help to understand the table and indicate some of the variations required for various types of apparatus and conditions. Determination of just what relay is to be specified, however, usually depends on a detailed consideration of the conditions surrounding the particular application.

Bearing temperature protection

The mechanical failure against which protection is most commonly provided is bearing failure. Any bearing trouble is usually manifested by overheating of the bearing bushing. The most commonly used method in stations is to mount a bearing temperature relay in each bearing. Operation of these relays closes a control circuit which actuates auxiliary relays to shut down the machine. In attended stations it may only give an alarm to inform of bearing heating.

The necessary control to shut down a rotating machine depends on the character of the machine. Tripping the circuit breaker supplying the motor is usually adequate to shut down induction motors while synchronous motors may require removal of the field current also. Synchronous condensers may also need some form of braking. Generators usually need an arrangement to shut down the prime mover, remove the field and apply mechanical brakes to bring the unit to a stop before the bearings fail. In some cases the field of a synchronous machine can be used to supply the required braking action.

TABLE 1
RECOMMENDATIONS FOR RELAY PROTECTION ON METAL-CLAD SWITCHGEAR
(ALTERNATING CURRENT ONLY)

SYMBOLS: □ NEMA MINIMUM RECOMMENDATION
○ NORMALLY RECOMMENDED AS DESIRABLE
△ AVAILABLE WHEN REQUESTED

TYPE OF UNIT / TYPE OF PROTECTION	SEE NOTE No.	GENERATOR	FEEDER	INCOMING LINE	TRANSFORMER	SYNCHRONOUS MOTOR	INDUCTION MOTOR
Bearing Temperature	1	△				△	△
Differential	2 & 3	②			③	②	△
Field Failure	4					□	
Overcurrent	5	△	□	□	□	□	□
Directional	6	△	△				
with volt. rest.	6	△					
Overfrequency	7	△				△	
Overvoltage	8	△				△	△
Phase Balance	9					△	△
Phase Sequence	10					△	△
Reverse Power	11	△	△	△	△		
Temperature						△	△
Thermal Overload						□	□
Undervoltage	8					□	□

See Notes to Tables on Page 23.

Differential protection

In general, differential protection is capable of giving the most complete protection against faults in the apparatus or circuit and take it out of service before extensive damage is done by the continuation of the fault current. The general principle is based on the fact that the current in a device or circuit should be the same at each end of the particular circuit being protected, and that any failure resulting in a fault will result in a short to ground or to another conductor which will upset this balanced condition.

One common way of using this differential principle on a rotating machine requires that both ends of each stator winding be brought out so that a current transformer can be placed in each lead. Obviously, if connected together in proper polarity, these two current transformers will generate the same secondary current which will circulate through both transformers and there will be no potential between the two secondary leads. However, if a fault to ground (on a grounded circuit), or a fault between phases should occur, the current in the two terminal connections to the phase winding will not balance since the fault current will not flow through one lead.

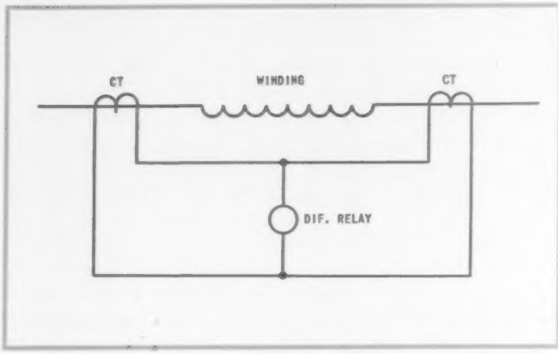
Connecting across the two secondaries of the current transformers will be a relay as shown in Figure 1. With no potential existing between the leads no current will flow in this relay. But when current in the two transformer secondaries is not the same, the difference in current supplied by the two transformers is forced through the connecting relay to close the circuit to a hand reset auxiliary relay which closes the tripping circuit of the breaker and usually opens the closing circuit. This auxiliary relay may have other contacts to initiate other operations desirable in shutting down a unit or prime mover.

Current transformers for differential protection must have similar characteristics and should not be used to supply other relays or instruments.

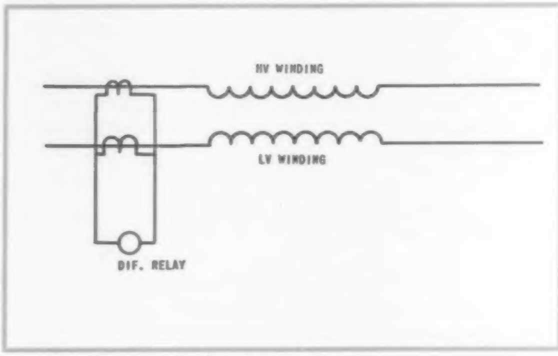
Differential relay protection offers choice

To effectively protect a synchronous machine the operation of the relay should not only open the breaker, but also kill the field excitation. With a generator it should also shut down the prime mover and stop the unit. Differential protection can be applied to either Y- or delta-connected machine.

With grounded three-phase machine three of the required six-current transformers are in the neutral ends of the phase windings at the machine. The other three are usually in the switchgear. With delta-connected machines all six current transformers should be adjacent to the machine to reduce the amount of cable required.



CURRENT RATIO differential protection diagram. **(FIGURE 1)**



TRANSFORMER DIFFERENTIAL protection diagram. **(FIGURE 2)**

General practice in applying differential protection to a transformer bank is to balance the primary current against the low voltage current for each phase, Figure 2. This, however, depends on how the transformer is connected. If not a straight Y-Y or delta-delta connection, special connections become necessary on the secondary side of the transformer to compensate for phase shift between primary and secondary windings.

The difference in the current between the high and low voltage windings must be taken into account in choosing the current transformer ratio to be used. Since the secondary current from the current transformer in the high voltage lead can rarely match the secondary current from the one in the low voltage lead exactly, the relay chosen must be less sensitive than need be the case in machine protection. A transformer differential relay with 50 percent sensitivity is built particularly for this application.

On transformers with more than two windings, or circuits with more than two incoming leads, special connections are necessary to balance the currents and special type relays may be required. All such circuits require careful analysis. Another application of this character is a bus with several incoming leads and several outgoing feeders.

In special instances the differential principle may be utilized employing differential in voltages or a combination of current and voltage.

Commonly used line, load protection

On synchronous machines, failure of excitation current may result in serious overheating or pulling out of step. Some method of taking the machine out of service under this condition is standard on synchronous motors. On generators and synchronous condensers used for voltage regulation this cannot necessarily be based on the absence of field current, since such machines may be operated down to zero or even excited in the reverse direction. In such cases one way is to use the absence of field excitation voltage to determine when a failure in the field circuit exists.

Overcurrent

It is usual practice to provide protection from overcurrents which may result from faults and be of such magnitude that the circuits cannot safely carry the current for any length of time. The most common form of overcurrent protection is to use a current transformer and overcurrent relay in each phase which trips the circuit breaker whenever a dangerous current is reached. This type of protection is simple and comparatively inexpensive.

It requires only one current transformer and one overcurrent relay for each phase. This current transformer can also be used with other relays and instruments. The usual overcurrent relay is of the induction type and can be obtained with various time characteristics and current ranges to suit the requirements of the application.

Other overcurrent relays with additional characteristics are available to meet certain applications. Some are built with a directional feature so they will only operate when the power flow is in one direction. Others are built with voltage restraint so they will operate only when the voltage is greatly reduced.

In general, straight overcurrent protection for generators is not desirable owing to the fact that straight overcurrent relays are apt to open the generator breaker under conditions where it is best to remove the fault by opening a breaker servicing only the affected circuit. This situation can be helped by using overcurrent relays with voltage restraint which will not trip the generator breaker if the voltage at the generator is maintained sufficiently high, as in the case where the fault is distant from the generator or is a partial failure. This form of protection is used by some engineers for bus protection where no differential protection is provided on the bus. If overcurrent protection is deemed desirable the use of voltage restraint relays is recommended, but in general where overcurrent protection is necessary only for internal faults it is more desirable to have differential protection. On small and intermediate type generators this internal fault protection is sometimes accomplished by the use of directional overcurrent relays. Differential protection should be furnished for all generators 1000 kva and over.

Directional overcurrent relays are recommended for feeder circuits where a loop circuit is used or there are two parallel feeders with circuit breakers at each end. In such cases a directional overcurrent relay can be used to open the breakers if a fault develops on a feeder and causes power flow into the feeder in the reverse direction.

Overfrequency

The most usual application of overfrequency protection is as an auxiliary protection against overspeed. When the frequency exceeds a certain predetermined value a frequency

relay can be used to trip the breaker and such other operations as may be desired, such as closing down a prime mover.

Although most prime movers have some kind of mechanical overspeed trip, overfrequency protection will guard against failure of these primary devices. Such precaution is particularly desirable in unattended stations.

Overload

In general, motors are usually much smaller than generating units and much more subject to being operated for extended periods under overload conditions. They should, therefore, be provided with overload protection. Usually this is done by using thermal overload relays. In case of sustained overloads which may be dangerous to the motor windings the relay will operate to open the circuit breaker supplying the motor. Very large motors may be provided with embedded detectors and permit the use of a temperature relay for this purpose.

In attended stations, generators are not usually provided with any overload protection as the operator can easily determine the load being carried by the generator and see that enough units are in service to carry the load. Also it is frequently desirable to carry overloads on generators for short periods. Additional protection for large generators can be obtained by some means of indication of the machine temperature so that the load can be reduced when the temperature becomes too high. This is best achieved by embedded detectors built into the stator windings and connected to a temperature indicator. In unattended stations a temperature relay should be provided which can be used to shut down the unit or give a signal at some attended point.

Automatic removal of transformers from service due to overloads is not generally practiced. If they are provided with embedded detectors, however, this may be done with a temperature relay and may be desirable. Large transformers usually have an indicator showing temperature of the oil.

Overvoltage

A voltage relay operating off a potential transformer can be used when the voltage exceeds a predetermined value, either to lower the field current in case of a voltage regulator failure or to give an alarm signal. In unattended stations it may close down the unit.

Undervoltage

Protection is normally supplied to prevent motors operating for long periods under conditions of serious undervoltage. If allowed to continue to operate under low voltage conditions they will not only heat up, but their maximum torque will be reduced, and they may not be able to pull the mechanical load to which they are connected. A voltage relay operating from a potential transformer can be used to trip the circuit breaker if the voltage drops too low.

Since frequently occurring momentary voltage fluctuations are relatively harmless, an induction type relay which will operate with a short time delay is usually adequate protection under such conditions. When the low voltage relay operates and trips the breaker, it is important that the motor cannot start up on restoration of voltage until started in the usual manner.

Phase balance and phase sequence

Phase balance protection to prevent operation with one phase open is desirable for many motors. Phase sequence pro-

TABLE 2

STANDARD RELAYS

USED ON METAL-CLAD SWITCHGEAR

(AC ONLY)

DESCRIPTION OF RELAY	TYPE PROTECTION NOTE No.	TIME CHARACTERISTIC NOTE 12						RELAY RESPONSIVE TO						RELAY TYPE DESIGNATIONS	
		INSTANTANEOUS OR NO DELAY	DEFINITE	INVERSE	VERY INVERSE	EXTREMELY INV.	HIGH SPEED	CURRENT	VOLTAGE	POWER	DIRECTION	FREQUENCY	DIFFERENTIAL	MFR. No. 1	MFR. No. 2
Auxiliary Relays															
2-Cir. Contacts		X						X						SC	PJC
2-Cir. Contacts		X							X					SV	PJV
Multi-Contact		X							X					MG-6	HFA
Make and Break		X							X					SG	HGA
Differential — Ind. Type															
Low Speed	2			X				X					X	CA	IJD
3-Winding Trans.	3			X				X					X	CA-4	HDD
Multi-Circ. Bus				X				X					X	CA-6	IFD-15A
High Speed	2						X	X					X	HA	CFD
Frequency — Over or Under	7											X		CF1	IJF
Overcurrent — Ind. Type	5		A	A	A			A						CO	IAC
Ind. Type	5					A		A						CO-10	IAC 77
Directional	6			A	A			A			X			CR	IBC
With Volt. Rest.	6			A				A	X					COV	
Short Time, No. Rest.				A				A						COH	IAC 16B
H.S. Directional	6						X	A			X			HRC	
Phase Balance	9	X		X				A			X			CM	1JC 51B
Phase Reversal	10	X							A		X			CP	ICR
Reclosing — 3 Rec. and L.O.														RC	AC-1
Reverse Power	11			A						A	X			CW	ICW
Temperature Relay				X				Exploring Coils						CT	CFT
Thermal Overload				X				A						BL	TMC 11A
Voltage — Over or Under	8			A					A					CV	IAV

A — Adjustable in time, current or voltage setting.

Notes to Tables

1. Machine must have bearing temperature relays mounted in bearings. Switchgear can be arranged to sound alarm or provide shutdown as desired.
2. Required matching current transformers in each phase winding at each end of winding (six- or three-phase machine). Can use three relays to operate on differential current.
3. Requires current transformer in HV and LV leads, relative current ratio to correspond to transformer voltage ratio. See discussion under Differential Protection if transformer other than two winding.
4. Usually inherent in motor field application control. See discussion under Field Failure.
5. Three overcurrent relays, may be used with characteristics to suit application.
6. Read comments under Overcurrent for application to Generators.
7. Either over- or underfrequency protection can be obtained using frequency relay.
8. Either over- or undervoltage protection, or both, can be obtained with a voltage relay.
9. Desirable on motors, to prevent single phase operation.
10. Certain motors must be protected so they cannot be started in the wrong direction. A phase reverse relay will do this. This will prevent starting in reverse but will not shut down in case of phase failure.
11. Reverse power relays can be used to prevent against prime movers being driven by their generators. Also to prevent power flow in one direction for any reason.
12. Where more than one time characteristic is indicated, relay can be obtained with any one characteristic indicated. Relays marked A are adjustable in voltage, current or time setting.

tection is available for protection against starting up a motor in the reverse direction.

Reverse power

In order to prevent a generator operating as a motor and continuing to drive the prime mover a reverse power relay may be used to shut down the unit. The same protection is sometimes put on a motor to prevent it being driven as a generator.

Tables and figures simplify specifications

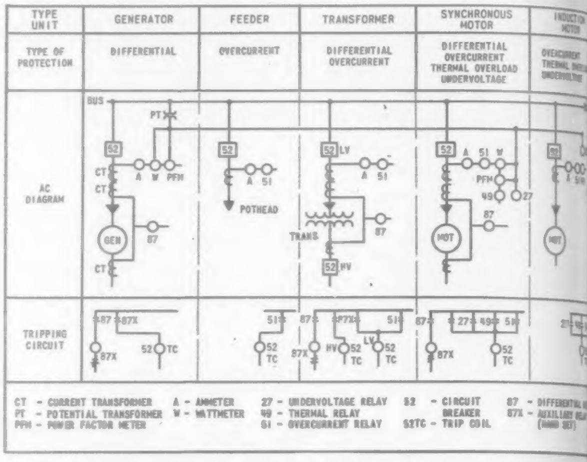
Table 1 is a reference table showing the types of protection applicable to usual types of metal-clad switchgear units. It also indicates the NEMA recommendation as to the minimum protection to be supplied.

Table 2 is a tabulation of some of the usual type of protective relays normally used on metal-clad switchgear and some of their major characteristics.

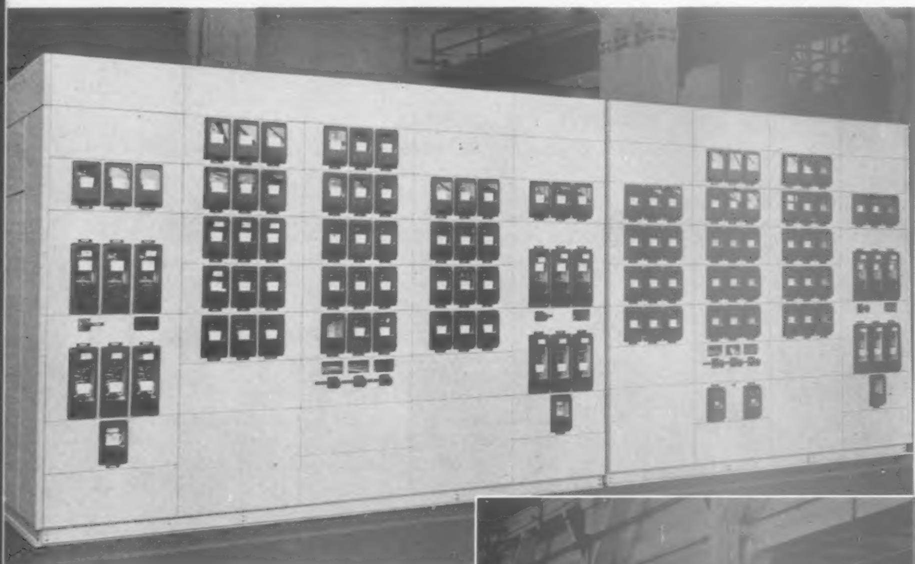
The notes apply to both tables and serve to tie in the relay with the type of relay protection in which it may be used.

Figures 1 and 2 are given to illustrate the fundamental application of differential protection.

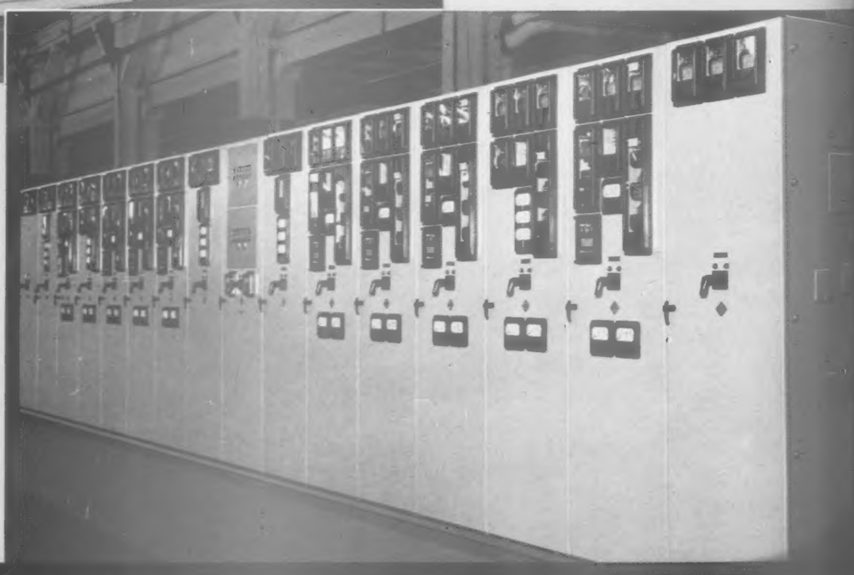
Figure 3 shows schematic diagrams of typical switchgear units to show various combinations of protective schemes. The minimum protection recommended for any type unit may be obtained from Table 1. The usual minimum of instruments are also shown in order to help in showing need for current and potential transformers.



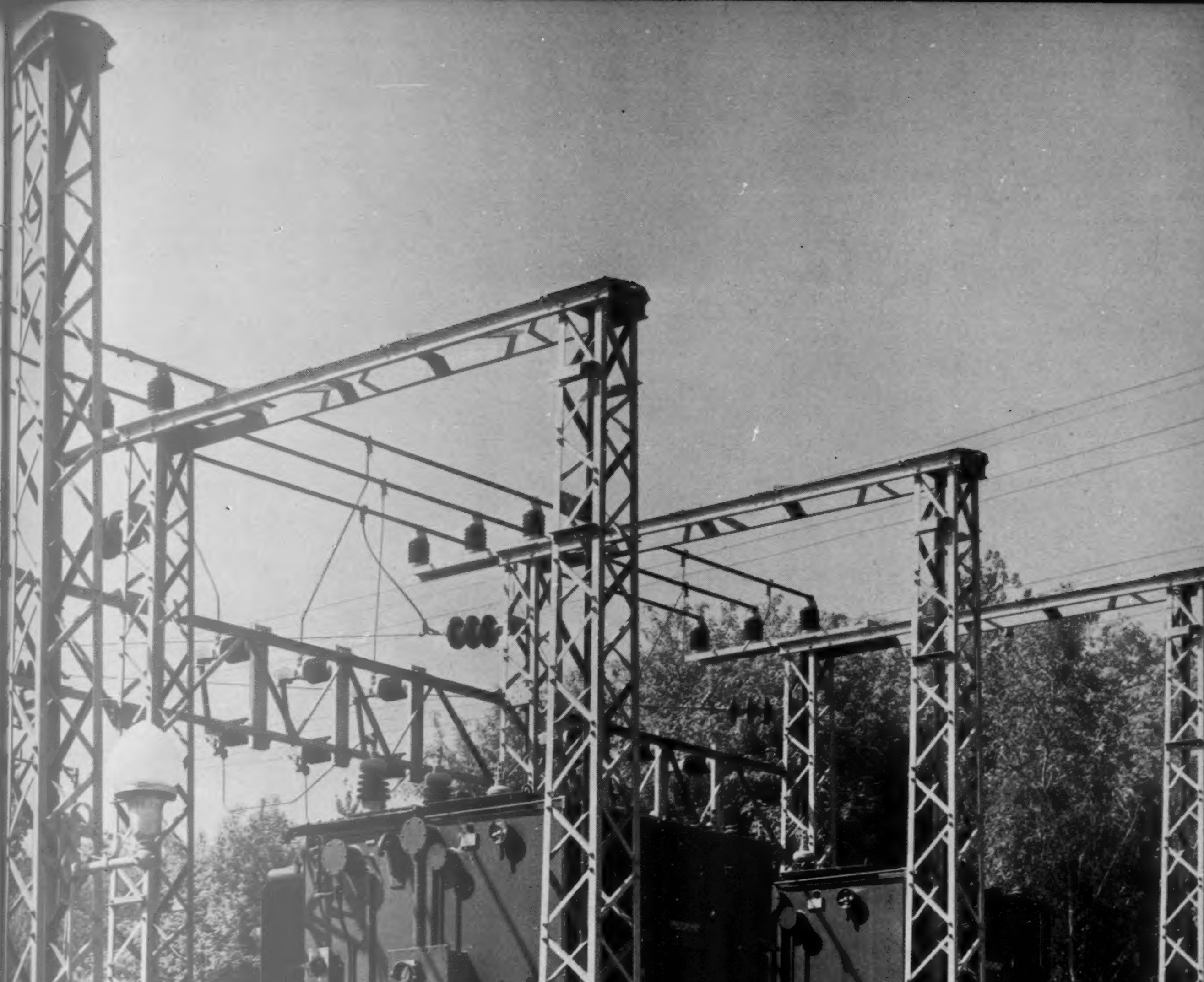
LINE DIAGRAMS for five typical metal-clad switchgear units with recommended relay and instrument equipment illustrates where current and potential transformers are required in various relay combinations. The diagrams also show the necessary tripping circuits for breakers. **(FIGURE 3)**



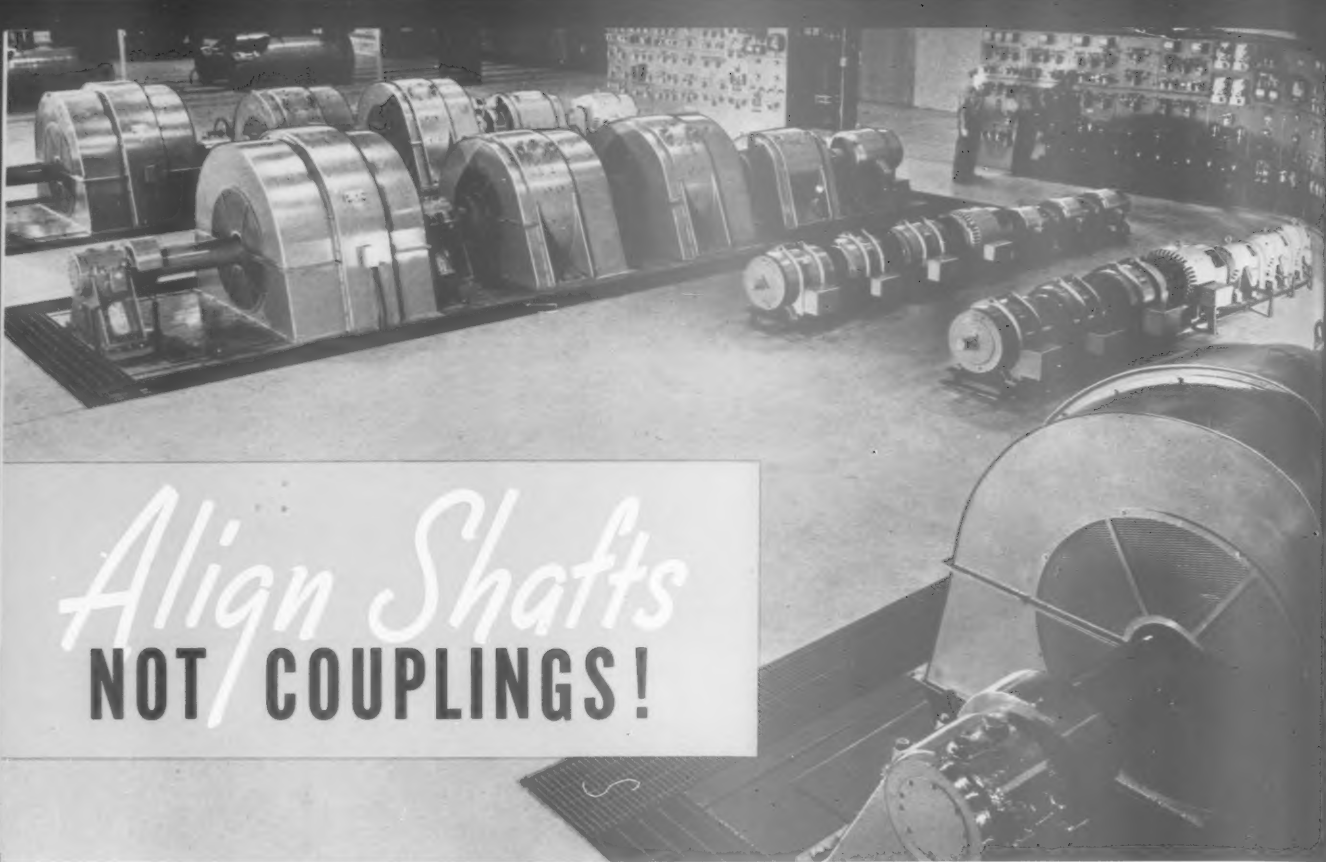
EACH RELAY SECTION of Duplex switchboard shown at left is a complete removable and interchangeable unit with terminal blocks. Replacement or relaying changes can be made easily and quickly, using standardized relaying combinations. These units are particularly suitable for utility service.



METAL-CLAD SWITCHGEAR lineup contains all of the necessary relays and instruments for controlling eight 4160-volt synchronous motors and incoming power and transformer units. Ranging in size from 700 to 3000 hp, motors drive centrifugal pumps at a large metropolitan water system.



STANDARD DESIGN of single circuit unit substations permitted their installation within the same bays utilizing the steelwork of the old single-phase transformers they replaced. Installed on the Pacific Coast, these 2000/2300-kva, three-phase, 60-cycle units with load ratio control provide increased capacity and complete regulation, switching and relaying facilities in space formerly occupied by the smaller capacity transformers. Two of six similar units to be used on the system, unit substations are equipped with by-pass switches so that the circuit breaker can be removed from service without interrupting flow of power.



Align Shafts NOT COUPLINGS!

by W. F. KING* and J. E. PETERMANN
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Proven methods and procedures show how to align shafts properly and dispel the old fallacy that coupling and shaft alignment are one and the same thing.

OBTAINING GOOD ALIGNMENT between two rotating shafts is impossible, if not properly approached. The difficulties arise not from the comparatively simple procedure of obtaining measurements, but from the attempts to analyze the data correctly. The typical data given below shows how accurate analysis properly applied assures correct shaft alignment.

The first thing to remember is that it is the shafts that need aligning, not the couplings. A coupling may be accurately machined, but after being shrunk or pressed onto a shaft, the coupling hub will almost invariably be eccentric with the shaft axis, for it does not deform symmetrically when assembled with an interference fit. While this condition will not affect the performance of a flexible coupling, it is obvious that alignment of the coupling hubs does not necessarily align the shafts. A correct procedure for aligning shafts is not dependent on the accuracy of the surfaces at which the measurements are taken. Figure 1 shows an exaggerated case of inaccurate surfaces.

To distinguish between the error of the coupling surfaces and misalignment, both shafts should be turned equal parts of a revolution (usually 90 degrees), while measurements between the couplings or shafts are taken at the same points on the surfaces for each interval. The reason for this is that the inaccuracies of the surfaces will rotate with the shafts and can be cancelled in analysis of the measurements. The misalignment, however, will remain constant in direction. If only one shaft is rotated, there must be positive assurance that the surfaces on the stationary shaft, to which measurements are made, are perfectly true. If neither is rotated, it must be assumed optimistically that both are perfectly true.

Double trouble needs double check

There are two types of misalignment, although the general case is a combination of both. Shown in Figure 2 these are:

1. Parallel or offset misalignment; the shaft axes are parallel but do not intersect.
2. Angular misalignment; the shaft axes intersect, but the shafts are not coaxial.

It follows that where these two conditions of misalignment occur, two distinct sets of measurements are needed to determine and to correct the misalignment. These measurements

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may be taken in various ways as outlined below, depending on conditions and the accuracy desired.

Usually one set each of axial and radial measurements is taken at intervals of one quarter turn of the shafts. For rigid couplings, the axial measurements should be taken at four circumferential locations for each position to check accuracy of the coupling faces, i.e., top, bottom, right and left.

A minimum of two axial measurements at each position is necessary to check alignment, if the shafts float axially while being rotated. However, this does not provide sufficient data to check the trueness of the coupling and should be used only with flexible couplings.

If only one axial measurement is taken at each position, the shafts must be held definitely against the bearing shoulders in one direction.

In the case of a rigid coupling with a pilot or spigot fit between coupling halves, which presumably does not permit parallel misalignment, only axial measurements are needed. However, it may be advisable to take radial measurements to check the accuracy of the pilot fit.

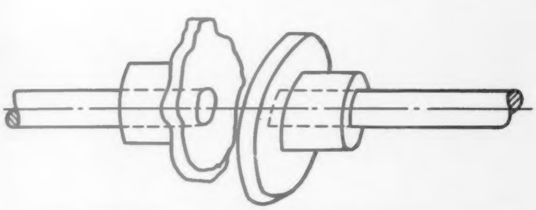
Although the shaft alignment may be checked by various means, as shown in Figure 3, the method of analyzing the measurements remains the same.

If there is a space between coupling hubs or if the radial measurement is across a span such that the ratio S/D (Figure 4) is 1/10 or more, the radial alignment measurements should be corrected for the error introduced in the radial measurement by the angular misalignment. The reason for this is apparent in Figure 4.

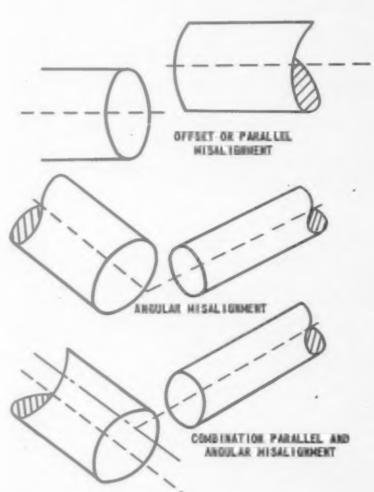
Unless the bracket used for the radial measurement with a dial indicator is short the deflection of the bracket should be taken into account. For measuring the deflection, the indicator bracket is attached to a bar having many times the flexural rigidity of the bracket. The indicator is set at zero on top of the bar and inverted. The reading in the inverted position will be twice the static deflection of the arm. The other alternative is to weigh the arm and then apply a pull of ⅜ the arm weight at the end of the arm. The deflection due to this pull is about equal to the static deflection of the arm. This procedure is shown in Figure 5.

Check alignment carefully

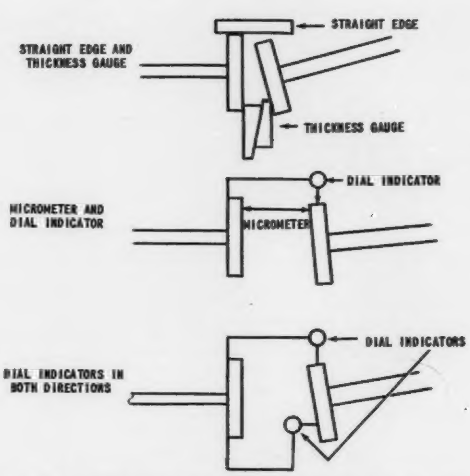
The half couplings should be match-marked to maintain the same relationship between the two shafts while they are rotated progressively one-fourth revolution for successive measurements. At each position the axial spacing of the coupling halves is gauged at four points: top, bottom, right



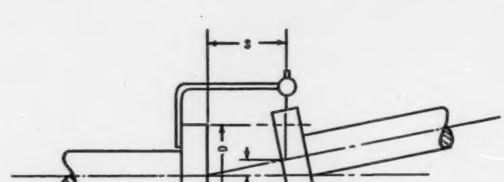
SHAFT ALIGNMENT is possible even in this exaggerated example of coupling surface inaccuracies. Drawing shows that alignment of couplings is no assurance that shafts are aligned. **(FIGURE 1)**



THREE COMMON TYPES of shaft misalignment frequently found in rotating equipment are shown above. Accurate measurements and proper analysis of data can be used to correct each case. **(FIGURE 2)**



THREE MOST EFFECTIVE methods of checking shaft alignment are shown above. Method depends upon the equipment and space available. Some components of each are interchangeable. **(FIG. 3)**



ANGULAR MISALIGNMENT illustrated in this measurement set-up drawing causes a radial runout which is proportional to distance "S." There is no parallel misalignment. **(FIGURE 4)**

TABLE I

ALIGNMENT DATA

$D = 10\text{-in.}$

$S = 5\text{-in.} \frac{S}{D} = .5$

$L_1 = 15\text{-in.} \frac{L_1}{D} = 1.5$

$L_2 = 60\text{-in.} \frac{L_2}{D} = 6.0$

VERTICAL DEFLECTION OF DIAL INDICATOR BRACKET = .002"

All Measurements Below are Multiples of 1/1000 Inch. Whole Inches Dropped.

ANGULAR ALIGNMENT CHECK

		POSITION	AXIAL MEASUREMENTS I	II	III	IV	Mean Diff.	Mean Diff. $\times \frac{S}{D}$ Correction for Parallel Alignment
MISALIGNMENT	VERTICAL	Top (T)	375	378	370	391	Open at Bottom	
		Bottom (B)	377	382	376	395		
		Diff. (T-13)	− 2	− 4	− 6	− 4	− 4	− 4 × .5 = − 2
	HORIZONTAL	Right (R)	375	380	371	390	Open at Left Side	
		Left (L)	378	381	374	395		
		Diff. (R-L)	− 3	− 1	− 3	− 5	− 3	− 3 × .5 = − 1.5

PARALLEL (OFFSET) ALIGNMENT CHECK

	Top	Right	Bottom	Left
Radial Measurements	0	13	6	− 3
Deflection of Indicator Bracket	− 2		+ 2	
Corrected Runout	− 2	13	8	− 3

MISALIGNMENT — VERTICAL

$$\frac{\text{Top} - \text{Bottom}}{2} = \frac{-2-8}{2} = -5$$

Angular Mean Difference × S/D = − 2

Resultant Offset − 7 (Low)

MISALIGNMENT — HORIZONTAL

$$\frac{\text{Right} - \text{Left}}{2} = \frac{13-(-3)}{2} = 8$$

Angular Mean Difference × S/D = − 1.5

Resultant Offset 6.5 (Right)

TABLE II

CORRECTION OF BEARING POSITIONS

VERTICAL				
BEARING No. 1				
	Angular	.004" × 1.5 =	.006"	Lower
	Parallel		.007"	Raise
		Net	.001"	Raise
BEARING No. 2				
	Angular	.004" × 6 =	.024"	Lower
	Parallel		.007"	Raise
		Net	.017"	Lower
HORIZONTAL				
BEARING No. 1				
	Angular	.003" × 1.5 =	.0045"	Left
	Parallel		.0065"	Left
		Net	.011"	To Left
BEARING No. 2				
	Angular	.003" × 6 =	.018"	Left
	Parallel		.0065"	Left
		Net	.0245"	To Left

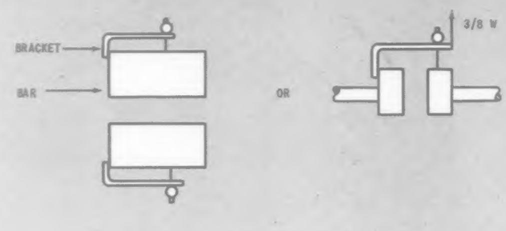
and left, and the radial relationship is measured at the same locations on the coupling surfaces. This data and other pertinent measurements, shown on symbols in Figure 6, are tabulated as shown in Table I.

Upon completing a full revolution of both shafts, it is well to check readings at the starting position, or better yet, to repeat the full set of measurements to be sure that the readings are consistent. Axial float of the shafts will not affect the result of axial measurements for the difference will remain unchanged.

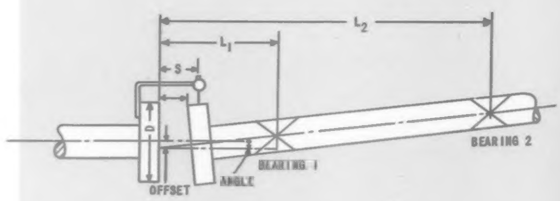
In figuring the adjustment to align the shafts, one shaft is considered to be fixed with respect to the location of its bearings. The other, the one to the right on Figure 6 and Figure 8, is to be adjusted to correct misalignment. Diameter "D" is the diameter of the circle on which axial measurements are taken. Space "S" is the distance from the face of the coupling on the fixed shaft to the location at which radial measurements are taken on the shaft to be adjusted.

Study alignment data

In the tabulation of alignment data, measurements and differences are positive when to the top and to the right; negative when to the bottom and to the left. The mean differences determined from the axial measurements represent the taper of the coupling gap, or angular misalignment, in units of 1/1000-inch across the diameter "D" in the horizontal and



EITHER OF TWO methods shown above can be used for correcting for bracket deflection. Readings obtained by each are sufficiently accurate. **(FIGURE 5)**



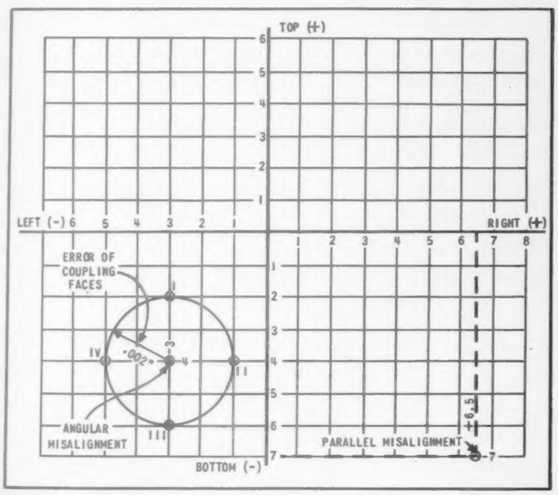
MISALIGNED SHAFT and dimensions needed to determine alignment correction from misalignment data (Table 1) are illustrated above. **(FIGURE 6)**

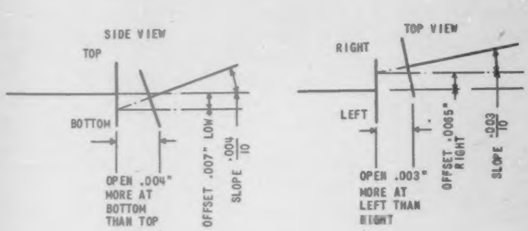
vertical directions. Runout error of the surfaces is cancelled in this analysis. The resultant offsets determined from the parallel alignment check are the amounts the shaft to be adjusted is displaced, parallel to the other shaft in the vertical and horizontal directions.

To ascertain the error of the coupling faces, that is, the extent to which the coupling faces will be out of parallelism when the shafts are accurately aligned, the differences obtained from the axial measurements at each position in columns I, II, III, and IV are plotted as on Figure 7. The four points plotted will fall on a circle, the center of which determines the angular misalignment based on the diameter "D." It will be noted, the arithmetic means of the differences shown on the table checks the center of the circle shown graphically. The radius of the circle represents the error of the coupling faces across the same diameter "D." This is the combined error of both half couplings for the relative angular relationship at which the alignment was checked. Obviously this error is of importance only with rigid couplings.

Parallel misalignment may also be plotted on the chart. Should it be desirable to determine the relative concentricity of the couplings, four radial measurements must be taken at each position and the differences plotted to form a similar circle diagram.

GRAPHICAL REPRESENTATION of angular and parallel misalignment and the error in coupling faces is shown below. Illustration represents a simplified method of determining the amount of misalignment. **(FIGURE 7)**



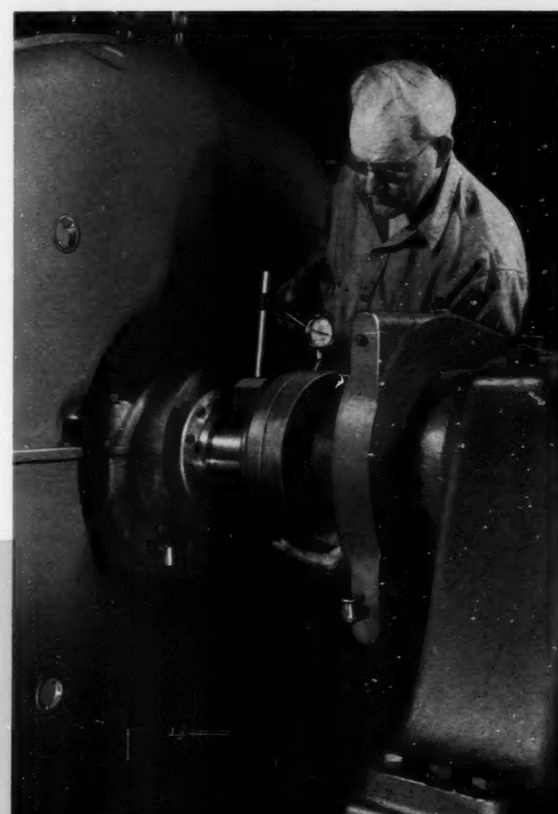


TOP AND SIDE VIEW of shafts shows pictorially both vertical and horizontal misalignment data listed in Table 1. **(FIGURE 8)**

Measure, analyze, correct faults

In correcting misalignment, the amount and particularly the direction in which the bearings should be adjusted can be visualized by a simple diagram of misalignment (Figure 8). Correction consists of a parallel shift of the shaft to be adjusted plus an angular swing about an imaginary pivot point on the face of the coupling on the fixed shaft. These can be combined into a single horizontal and vertical adjustment of each bearing (Table II). In computing the correction, plus and minus signs used in Table I are disregarded. Angular misalignment is multiplied by the factor L/D as shown in Figure 6. In the case of a single bearing electrical machine, the correction computed for bearing (1) can apply to the center of the yoke for the purpose of maintaining uniform air gap.

Detrimental effects arising from misalignment should not be underestimated. Flexible couplings are not completely free of restraint since the flexibility is accomplished either with sliding or flexural members. These members transmit frictional or flexural forces to the shafts, in proportion to the degree of misalignment, which can cause vibration at the bearings and elsewhere. Misalignment of rigid couplings will cause abnormal bearing loading with reduction in life of the bearings, and bending stresses in the shafts which at times lead to a shaft fatigue failure. In a severe case of misalignment it is impossible to obtain a running balance.



SHAFTS FOR COMPLETE m-g sets and other units are aligned at the factory, as shown above. Shafts for large turbo-generators and motors which drive a variety of equipment, on the other hand, must be aligned in the field.

V-Belt DRIVE FUNDAMENTALS *for Engineers*

by **FRANK H. RUMBLE**
Texrope Drive Dept.
Allis-Chalmers Mfg. Co.

Properly engineered V-belt drives provide economical power transmission with considerable savings in space and equipment.

WHILE THE ENGINEERING of a V-belt drive is fundamentally within the realm of mechanical engineering principles, the selection of the proper drive and reasons for so doing are of interest to the electrical engineer as well. Besides being used on motors, the modern V-belt drive is frequently used on other types of electrical equipment such as exciters and generators. Selection of the proper drive has much to do with the efficient operation and service life of such equipment.

A further fact of interest to the electrical engineer and the average user is the extent to which the selection of an adequate V-belt drive for any application is based upon the characteristics of the motor used. The motive force, of course, can be any type of prime mover, but as a matter of record it is estimated that more than 98 percent of the multiple V-belt drives in use transmit power from individual electric motors.

The principles of engineering a V-belt drive are well established. Consequently, an adequate drive is usually obtained by following the instructions outlined in the catalog of any reputable manufacturer of V-belts or sheaves. While methods may vary, all are based on the same fundamental principles of belt ratings, speed, horsepower, and characteristics of driver and driven machine.

Cheaper drives are not always economical

It is not the purpose of this article to explain in detail *how* to engineer a V-belt drive but to point out *why* various factors must be considered in order to select the most economical as well as the best engineered drive.

The most economical V-belt drive for any application is one that renders the most efficient service over the longer period of

TABLE I

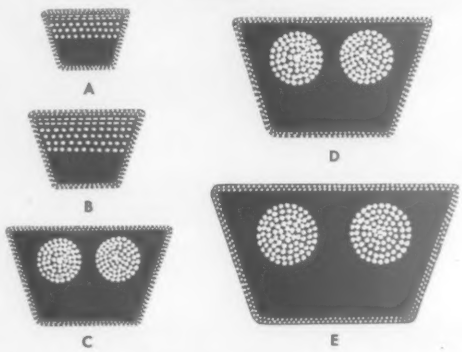
PRIME MOVER	Starting Torque	Pull-Out Torque	Constant or Variable Speed
Squirrel Cage Motors			
Normal Torque (Line Start)	110 to 150%	200 to 250%	Constant
Normal Torque (Compensator Start)	110 to 150%	220 to 250%	Constant
High Torque	200 to 300%	200 to 400%	Constant
Wound Rotor Motor (Slip Ring Type)	150 to 250%	200 to 250%	Variable
Synchronous Motors			
Normal Torque	110 to 125%	150 to 250%	Constant
High Torque	160 to 200%	250 to 400%	Constant
Single Phase Motors			
Repulsion and Split-Phase	230 to 500%	250 to 400%	Constant
Capacitor	150 to 200%	175 to 200%	Constant
Direct Current Motors			
Shunt Wound	50 to 100%	150% Peak Momentary Load	Both
Compound Wound	50 to 100%	150% Peak Momentary Load	Both

TABLE II — SERVICE FACTORS

Applications	Electric Motors										Engines			
	AC								DC		Gas and Diesel			
	Squirrel Cage			Wound Rotor (Slip-Ring)	Synchronous		Single Phase							
	Normal Torque Line Start	Normal Torque Compensator Start	High Torque		Normal Torque	High Torque	Repulsion and Split-Phase	Capacitor	Shunt Wound	Compound Wound	4 or More Cyl. Above 700 rpm	4 or More Cyl. Below 700 rpm	Steam	Line Shafts and Clutch Starting
Agitators — Paddle-Propeller														
Liquid	1.0	1.0	1.2	...	...	...	...	...	...	...	...	...	...	...
Semi-Liquid	1.2	1.0	1.4	1.2	...	...	...	...	...	...	...	...	...	...
Brick and Clay Machinery														
Auger and De-Airing Machines, Cutting Table, Rolls, Granulator	...	1.2	1.4	1.4	...	...	...	...	1.4	...	...	...	...	2.0
Mixer, Dry Press	...	1.2	1.6	1.4	...	...	...	...	...	...	...	...	...	...
Pug Mill	1.5	1.3	1.8	1.5	...	...	...	...	...	...	...	...	...	...
Bakery Machinery	1.2	...	...	...	...	...	1.2	1.0	...	...	...	...	...	...
Compressors														
Centrifugal or Rotary	1.2	1.2	...	1.4	1.4	...	1.2	1.2	...	1.2	...	...	...	...
Reciprocating — 3 or More Cylinders	1.2	1.2	...	1.4	1.4	...	...	...	1.2	...	...	...	...	...
1 or 2 Cylinders	1.4	1.4	...	1.5	1.5	...	...	...	1.2	...	...	...	...	...
Conveyors														
Apron, Bucket, Pan, Elevator	...	1.4	1.6	...	...	...	...	...	1.4	...	...	...	...	1.6
Belt (Ore, Coal, Sand, etc.)	...	1.2	1.4	...	...	...	...	...	1.2	...	...	...	...	1.4
Flight	...	1.6	1.8	...	...	...	...	...	1.6	...	...	...	...	1.8
Oven, Belt (Light Package)	...	1.0	1.1	...	...	...	...	...	1.0	...	...	...	...	1.2
Crushing Machinery														
Jaw, Gyratory and Cone Crushers, Crushing Rolls, Ball, Pebble and Tube Mills	...	1.4	1.6	1.4	1.4	1.6	...	...	...	1.4	1.4	...	...	1.6
Fans and Blowers														
Centrifugal, Induced Draft, Exhausters	1.2	1.2	...	1.4	...	...	...	...	1.4	...	1.4	...	1.5	1.5
Propeller, Mine Fans	1.6	1.6	1.6	1.6	...	1.8	...	...	1.4	...	1.6	...	...	...
Positive Blowers	1.6	1.6	...	2.0	2.0	1.8	...	...	...	...	1.6	...	...	...
Flour — Feed — Cereal Mill Machinery*														
Bolters, Sifters, Separators	1.0	1.0	...	...	...	...	...	...	...	...	...	...	...	...
Grinders, Hammermills, Purifiers, Reels, Mainline Shaft	1.4	1.4	1.6	1.4	1.4	...	...	...	...	...	1.8	...	...	...
*Chokable Equipment—Service Factor of 2.0														
Generators and Exciters	1.2	...	...	...	...	...	...	...	1.2	...	*	...	1.4	1.4
Laundry Machinery	1.2	...	...	...	...	...	...	...	...	1.2	...	...	...	...
Line Shafts	1.4	1.4	...	1.4	1.4	2.0	1.4	1.4	1.4	1.4	1.6	...	1.6	1.6
Machine Tools														
Grinders, Boring Mills, Milling Machines, Planers, Shears	1.2	...	...	1.4	...	...	1.2	1.2	1.2	1.2	...	...	...	...
Lathes, Screw Machines, Cam Cutters, Shapers, Drill Press, Drop Hammers	1.0	...	...	1.2	...	...	1.0	1.0	1.0	1.0	...	...	...	...
Mills														
Pebble, Rod, Ball, Roller	...	1.4	1.6	1.4	...	...	...	...	...	1.4	...	...	...	1.6
Flaking Mills, Tumbling Barrels	...	1.6	1.6	1.4	...	...	...	...	...	1.4	...	...	...	1.6
Oil Field Machinery														
Slush Pumps, Pumping Units, Pipe Line Pumps — Centrifugal	1.2	1.2	1.4	...	...	...	...	...	1.4	1.4	1.4	1.6	1.4	1.6
Draw Works (Intermittent)	...	...	...	...	...	...	...	...	1.3	...	1.0	1.0	...	...
Hoisting Service Factor Based on Total Engine hp (Continuous Rating)														
Electric Drive Factor based on Continuous Rating of Motor.														
Paper Machinery														
Jordan Engines	1.5	1.3	1.8	1.5	1.6	1.8	...	...	1.5	1.5	...	...	...	...
Beaters, Paper Machines	1.4	1.4	...	1.5	...	...	...	...	1.5	1.5	...	...	...	1.8
Calenders, Agitators, Dryers	1.2	1.2	1.4	1.2	...	...	...	...	1.2	1.2	...	...	...	1.6
Printing Machinery	1.2	1.2	...	1.2	...	...	...	...	1.2	1.2	...	...	...	...
Pumps														
Centrifugal, Gear, Rotary	1.2	1.2	1.4	1.4	...	...	1.2	1.2	1.2	...	1.2	...	...	...
Reciprocating — 3 or more Cylinders	1.2	1.2	...	1.4	1.4	1.6	...	...	...	...	1.8	...	1.8	...
1 or 2 Cyl., Dredge Pump	1.4	1.4	...	1.4	...	...	...	...	...	...	2.0	...	2.0	...
Sawmill Machinery														
Log Canter, Log Jack, Cutoff Saws, Trimmers, Slashers, Swing Saws	1.4	1.4	...	1.4	...	...	...	...	1.4	...	...	...	...	...
Band Mill, Circular, Hogs, Resaw	2.0	1.6	...	1.8	...	1.6	...	...	1.8	...	...	...	...	...
Edgers	1.6	1.6	...	1.6	...	1.6	...	...	1.6	...	...	...	...	...
Rubber Plant Machinery	1.4	1.4	1.4	1.4	...	1.8	...	...	...	...	...	2.0	...	...
Screens	1.2	1.2	1.4	...	...	...	...	...	...	...	...	...	...	...
Textile Machinery														
Spinning Frames, Twisters	1.9	...	1.8	...	...	...	...	...	...	...	...	...	...	...
Looms, Warpers, Reels	1.2	...	...	...	...	...	...	...	...	...	...	...	...	...

* If drive is from engine to generator of equivalent horsepower rating, use a 1.2 service factor. If drive is power take-off from engine of horsepower much greater than that of generator or exciter, use a service factor 2 × rating of the driven machine.

TABLE III



time. The V-belt drive that is best from the engineering standpoint is almost always lowest in first cost as well as maintenance. Nominal horsepower and rpm of the motor provide the starting point in determining the ultimate design of a V-belt drive. In addition, the designer also has to consider these additional factors:

1. Characteristics of the motor and driven machine.
2. Overload capacity.
3. Sizes of belts and sheaves.
4. Belt velocity.
5. Arc of contact.
6. Conditions under which the drive operates.

V-belt drive selection must be based on the motor and load factor as well as on horsepower and speed. Size and number of belts should not be selected on the basis of motor nameplate rating alone.

Taking up the above points in order, the first thing to be noted is the manner in which the characteristics of the motor can affect the selection of the drive. Table I lists the characteristics of the various types of motors under average operating conditions. For example, it makes a difference whether the driving unit is a squirrel cage motor with high starting torque, a dc motor with comparatively low starting torque load, or perhaps a slip ring motor with inherent capacity to withstand considerable overloading. Some types require more overload capacity in the drive than others.

Similarly, the load thrown on the drive in starting and running depends on the type and characteristics of the driven machine. The shock load of a crusher, for instance, requires more reserve horsepower-transmitting capacity in the drive than a smoother operating machine tool or centrifugal pump. A conveyor may pose still another problem. Considerably more power is often needed to start a load than to drive it at normal speed.

The peculiarities of both the prime mover and driven machine, then, as well as the nominal horsepower, must be taken into account in determining the total capacity that a drive should have to give satisfactory service. From all these conditions service factors have been computed that indicate the overload capacity to add to the nominal drive horsepower in each case.

Table II shows a typical service factor listing for various types of prime movers. To arrive at the "actual" horsepower capacity to be used, multiply the rated horsepower of the motor (nameplate rating) by the service factor. This will insure the proper margin of safety. When in doubt, it is better to run the risk of overbelting a drive rather than to underbelt it.

Bare minimums are risky

Proper engineering of drives requires adequate belt and sheave sizes for both economy and efficiency. Reducing the sizes of either for first cost saving usually increases the overall cost beyond justifiable limits. Tables III, IV, and V show the belt and sheave sizes best suited for a variety of applications.

Which of the five standard sizes (cross section) of V-belts (A, B, C, D, or E, Table III) to use depends upon the horsepower of the drive and the speed of the motor or driven machine, whichever is the greater. Table IV is a typical V-belt suggestion chart, which recommends the belt section for different speeds with various sized motors. Based on nominal horsepower, it is a result of experience in engineering thousands of drives. While there may be some exceptions, its recommendations are usually found to be correct and, in most cases,

TABLE IV

GENERAL TEXROPE BELT SUGGESTION TABLE

Motor Hp	Motor or Driven Machine Speed Whichever is the Greater												
	3600	3200	2800	2400	2000	1800	1450	1200	900	720	600	514	450
½–¾	A	A	A	A	A	A	A	A	A	B	B	B	B
1–1½	A	A	A	A	A	A	A	A	A	B	B	B	B
2–3	A	A	A	A	A	A	A	A	B	B	B	B	B
5	A	A	A	A	A	A	A	A	B	B	B	B	B
7½	B	B	B	B	B	B	B	B	B	B	B	B	B
10	B	B	B	B	B	B	B	B	B	C	C	C	C
15	B	B	B	B	B	B	B	B	B	C	C	C	C
20	B	B	B	B	B	B	B	B	B	C	C	C	C
25	B	B	B	B	C	C	C	C	C	C	C	C	C
30	B	B	B	B	C	C	C	C	C	C	C	C	C
40	B	B	B	B	C	C	C	C	C	C	C	C	C
50	B	B	B	B	C	C	C	C	C	D	D	D	D
60	B	B	B	B	C	C	C	C	C	D	D	D	D
75	B	B	B	B	C	C	C	C	C	D	D	D	D
100	B	B	B	B	C	C	C	D	D	D	D	E	E
125	B	B	B	B	C	C	C	D	D	D	D	E	E
150	B	B	B	B	C	C	C	D	D	D	D	E	E
200	B	B	B	B	C	C	C	D	D	E	E	E	E
250 and Over	B	B	B	B	C	C	C	D	D	E	E	E	E

Note: The belt sections suggested for higher speeds indicate the belt section which can operate satisfactorily without exceeding 5000 ft/min belt speed and without overflexing the belts on too small diameter sheaves.

TABLE V-a

Permissible Minimum Sheave Sizes	
A	3.0 inch
B	5.4 inch
C	9.0 inch
D	13.0 inch
E	21.6 inch

TABLE V-b

Recommended Minimum Sheave Sizes	
A	4.0 inch
B	6.0 inch
C	10.0 inch
D	14.0 inch
E	23.0 inch

to offer the only logical choice in selection of the proper belt section.

Table V-a shows the "permissible" minimum V-belt sheave pitch diameters usually advocated. Sheaves smaller than these can be used with the various size belts only at a great sacrifice of belt life. The reason for this is that sheave diameters have a definite relationship to the width and thickness of the belts used on any V-belt drive. Standard rubber V-belts are constructed of fabric, cord and rubber compound in proportions which experience has shown to stand up longest under the work the belts are designed to do. The bending of a V-belt in a natural, easy arc determines the smallest sheave that can be used without distorting the belt. If it is bent beyond this "easy arc" by use on a sheave whose diameter is too small, its super-structure is disarranged and internal friction causes it to heat and deteriorate.

Laboratory tests and service records show that reasonable belt life can be expected with sheaves as small as the permissible minimum. If possible, it is better to use sheaves somewhat larger than the minimum. Table V-b shows the typical minimum pitch diameters for each belt section. Use of the larger diameter sheaves means less flexing of the belts, reduction of internal heat and friction and, consequently, longer belt life. For example, use of a 5.4-inch or a 4.6-inch sheave with "B" section belts is not the difference between success or failure of the drive. It will operate. But use of a 6.0-inch instead of a 4.6-inch sheave will make considerable difference in the life of the belts. If belts on a 4.6-inch sheave have a life of two years, under otherwise favorable circumstances, it would not be unusual with a 6.0-inch sheave for the drive to have a belt life of four to six years or more.

Larger diameter sheaves may cost more, but belts do not need to be replaced as frequently. The cost of replacing only one set of belts usually offsets the difference in cost of slightly larger sheaves.

Belt velocity affects hp capacity

The maximum diameter of sheaves used on a drive is governed by space limits and belt velocity. The first condition requires little explanation. If space does not permit as large a diameter sheave as desired, the only other choice is to try to use a smaller one with grooves for enough belts to drive the load safely. Such drive may not be the most economical, but it will be the best engineered for existing conditions. Belt velocity requires more detailed explanation. Between practical limits, the larger the diameter of the driving sheave, the greater the belt velocity and the more horsepower each belt of the drive is capable of transmitting. For greatest efficiency belts should not travel too fast or too slow. What are the practical limits that govern proper belt velocity? The horsepower rating tables for standard belts usually show a recommended belt velocity of 1000 to 5000 feet per minute.

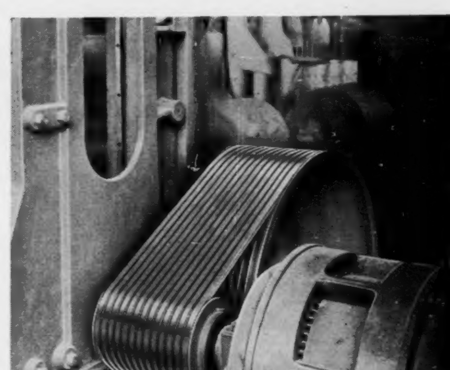
There is a reason for these limits. A belt at slow speed transmits less horsepower than when it is traveling faster. So a multiple V-belt drive as a whole requires more belts when speed is low. Since the power rating of a belt is quite low at a velocity of less than 1000 feet per minute, it is not economical nor good engineering practice to go below this point on most drives.

An equally good reason exists for limiting maximum belt velocity. As belt speed approaches and exceeds 5000 feet per minute, the tension is increased and centrifugal force tends to stretch the belts and throw them away from the grooves. This lessens the effective arc of contact on the sheaves and an appreciable part of the tractive effect is lost. Safety is another consideration. Most cast iron sheaves are constructed to withstand safely a rim speed not in excess of 5000 feet per minute. While special drives are sometimes constructed for use at lower or higher speeds, it is best to stay within the recommended limits on the average drive.

From the above it can be seen that belt velocity and sheave diameters are opposite sides of the same coin. One depends to a large extent upon the other. Sheave diameters should be large enough to insure good belt life, yet not so large as to produce excessive belt velocity. Larger diameter sheaves sometimes permit the use of fewer belts on a drive. This not only reflects a saving on both the original cost and replacements, but actually lowers initial cost of the complete drive. Part of the saving is effected in the lower cost of the sheaves. Because of machining costs it is almost always true that sheaves of slightly larger diameter but with few grooves are lower in cost than sheaves of slightly smaller diameter but with more grooves.

To illustrate how larger diameter sheaves affect the horsepower-transmitting capacity of a drive, consider, for instance,

DOUBLE V-BELT DRIVE from one generator transmits power to two exciters simultaneously. One unit provides excitation current to the generator itself and the other provides excitation to a large synchronous motor located in back of the generator.



"SPEED-UP" DRIVE from large generator permits use of small, high-speed exciter which occupies little space and provides a highly efficient, economical and compact installation.

D section belts on a 13.0-inch sheave driven by a 1150-rpm motor. Each belt will have a rating of 15.3 horsepower. Used on a 14.0-inch sheave each belt would have a rating of 17.9, or 2.6 horsepower more for each belt. On the first drive eight belts have a total rating of 122 horsepower, while on the second drive only seven belts have a total of 125 horsepower. The second drive not only has a greater total horsepower-transmitting capacity and is a better engineered drive, but is actually lower in price.

Similarly, on certain drives, a fewer number of larger section belts on larger diameter sheaves often have equal or greater horsepower-transmitting capacity than a greater number of smaller section belts on smaller diameter sheaves. Where this is true, the drive with the larger belt section is often preferable from an engineering standpoint and, in many cases, is lower in first cost.

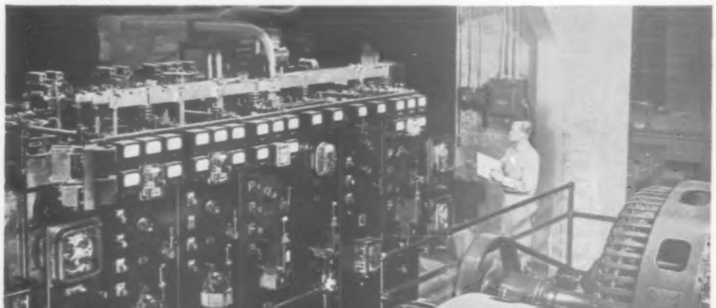
Drives offset operating conditions

The arc of contact of the belts on sheaves must be taken into account when determining the actual horsepower-transmitting capacity of each belt of the drive. Horsepower ratings for the different section V-belts are based on a 180-degree arc of contact. If one sheave is smaller than the other, the belt will have less than 180 degrees contact on it and, consequently, will have less horsepower-transmitting capacity. How much less can be calculated easily from the formula for finding effective arc of contact appearing in any V-belt catalogue. For example, the horsepower rating of a B section belt at a velocity of 4000 ft/min on a 5.4-inch sheave at 180 degrees arc of contact is 4.0. The formula shows that the same sheave with 150-degree arc of contact has only .92 effectiveness or $.92 \times 4.0 = 3.68$ horsepower per belt. With the exception of 1 to 1 ratio drives, one sheave of every V-belt drive is smaller than its companion sheave and will have less than 180-degree arc of contact. This fact should always be considered in calculating the total horsepower-transmitting capacity of the drive.

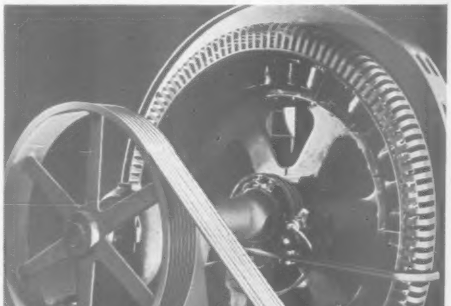
It is well to know the conditions under which a drive will operate and, if these are abnormal in any way, parts can be selected which are especially designed to solve the problem. Designers have long been aware of the varying conditions of operation and have designed and engineered the several parts of the drive to best meet the various needs. This is particularly true of the V-belts themselves. If the drive must operate where explosion hazards exist, belts are available with the cover impregnated with a static-conducting material. Such cover tends to conduct any static charge to the motor or the driven-unit frame where it can bleed to ground. The frictional contact of any belt on a pulley or sheave may generate static electricity which, if allowed to build up, might cause a spark. Use of static-conducting V-belts reduces this hazard by bleeding off the static.

If space limitations or other factors require the use of higher than ordinary horsepower capacity per belt, regular high capacity belts are available. These have a horsepower-transmitting capacity of 40 percent more than standard belts, but usually have a higher cost. Steel cable belts with a minimum amount of stretch are often advantageous on a fixed center drive. If the drive must operate in an oil atmosphere or is subject to contact with oil or grease, special oil-resisting or oil-proof belts should be used. Though higher in first cost, the selection of parts which have been especially designed to meet unusual operating conditions may conceivably double or triple the useful life of the drive.

If in doubt on any point it is well to consult engineers especially trained in all phases of V-belt application. The convenient tables appearing in standard catalogues and handbooks are usually for average conditions and cannot always take every factor into consideration. Close study of the conditions, coupled with practical experience, often helps in selecting the one best drive for an application.



PROPER USE OF V-BELT drives conserves space by permitting exciters to be placed alongside generators rather than having them take up aisle space in front of generators, as in the case of direct-connected generators.



ACCESSIBILITY for maintenance and inspection is one advantage of using V-belt drives to connect a large generator to a small exciter. Easy installation is another gain.

ALLIS-CHALMERS
"Certified"
SERVICE

ALABAMA
Birmingham—Elec. Repair & Serv. Co.
Montgomery—Standard Electric Co.

ARIZONA
Bisbee—Copper Electric Co. Inc.
Phoenix—Daley Electric Company

CALIFORNIA
San Diego—Calif. Elec. Works
Los Angeles—Larsen-Hogue Elec. Co.
Oakland—T. L. Rosenberg Co.
San Francisco—Weidenthal-Gosliner

COLORADO
Denver—Baker Electric Company

CONNECTICUT
Hartford—Charles H. Leppert
Waterbury—Elec. Motor Repair Co.

FLORIDA
Jacksonville—Turner Electric Works
Miami—Peninsular Armature Works
Tampa—Tampa Armature Works

GEORGIA
Albany—Georgia Electric Co.
Atlanta—Bearden-Thompson Elec. Co.
Columbus—Smith-Gray Electric Co.

ILLINOIS
Chicago—Chicago Electric Co.
Marion—Giles Armature & Elec. Wks.
Mt. Vernon—Dowzer Electric

INDIANA
Indianapolis—Scherer Electric Co.
Evansville—Evansville Elec. & Mfg. Co.

IOWA
Sioux City—Smith Elec. & Supply Co.

KANSAS
Salina—Cent. Kans. Elec. Mach. Co.
Wichita—Tarrant Electric Mach. Co.

LOUISIANA
New Orleans—Industrial Elec., Inc.
Shreveport—Shreveport Arm. & Elec.

MAINE
Brewer—Stanley J. Leen Co.

MARYLAND
Baltimore—Keystone Electric Co.

MASSACHUSETTS
Lawrence—Roland B. Glines Co.
Roslindale—Ranney Electric Motors
Springfield—Elec. Motor Repair Co.

MICHIGAN
Grand Rapids—Grand Rapids Ind. Elec.
Detroit—Stecker Electric Company

MINNESOTA
Duluth—Mielke Electric Works
Minneapolis—Parsons Elec Co.

MISSISSIPPI
Vicksburg—Ludke Electric Co., Inc.

MISSOURI
Kansas City—Boese-Hilburn Elec. Co.
St. Louis—French-Gerleman Elec. Co.
Springfield—Springfield Elec. Serv.

NEBRASKA
Omaha—Omaha Electrical Works

NEW HAMPSHIRE
Concord—A. S. Tracy

NEW JERSEY
Atlantic City—Charles A. Buckley
Paterson—Elec. Service Repair Co.
Trenton—Lockwood Elec. Motor Serv.

NEW MEXICO
Albuquerque—Powell Electric Co.

NEW YORK
Buffalo—Robertson Electric Co.
Jamestown—A. E. Westburgh
Mt. Vernon—H. A. Schreck, Inc.
New York—Consol. Elec. Motor Co.
Rochester—Vanderlinde Elec. Corp.
Utica—Mather, Evans & Diehl Co.
Watertown—Watertown Elec., Inc.

NORTH CAROLINA
Charlotte—Southern Elec. Service Co.
Greensboro—Southern Elec. Serv. Co.
Rocky Mount—Hammond Elec. Co.

NORTH DAKOTA
Fargo—Minnkota Electric Serv. Co.

OHIO
Cincinnati—Cincinnati Elec. Equip. Electric Service Co.
Akron—A-C Supply Co.
Toledo—Romanoff Elec. Motor Serv.
Youngstown—Winkle Electric Co.

OKLAHOMA
Miami—Miami Armature Works
Oklahoma City—Southwest Elec. Co.
Tulsa—Smith-Milligan Electric Co.

OREGON
Eugene—Kalen Electric & Mach. Co.
Portland—Milwaukee Mach. Co.

PENNSYLVANIA
Johnstown—Universal Elec. Mfg. Co.
Osceola Mills—Mid-State Elec. Eng. Co.
Philadelphia—Elec. App. & Repair Co.
Pittsburgh—Penn. Elec. Coil Corp.
York—Industrial Electric Company

SOUTH CAROLINA
Greenville—Southern Elec. Serv. Co.
Spartanburg—Southern Elec. Serv. Co.

SOUTH DAKOTA
Sioux Falls—Electric Motor Repair

TENNESSEE
Columbia—Middle Tenn. Arm. Wks.
LaFollette—Standard Arm. Works
Memphis—Indus. Elec. & Supply Co.

TEXAS
Amarillo—G. E. Jones Elec. Co.
Beaumont—Elec. Mach. & Repair
Dallas—Industrial Elec. Equipment Co.
El Paso—B & M Machinery Co.
Fort Worth—Central Electric Co.
Houston—Roy A. Berentz Co.

UTAH
Salt Lake City—Diamond Electric

VIRGINIA
Richmond—Wingfield & Hundley
Roanoke—Virginia Armature Co.

WASHINGTON
Spokane—Lee F. Austin Company

WEST VIRGINIA
Charleston—Charleston Elec. Supply
Fairmont—Central Elec. Repair Co.

WISCONSIN
Green Bay—Beemster Electric Co.
Milwaukee—Dietz Electric Co.
Wausau—Electric Motor Service
Wisconsin Rapids—Staub's Elec. Wks.

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